IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re US Appln. of : Kenichiro SUZUKI et al.

U.S. Application Serial No. 09/869,107 Filed: December 17, 2001

International Application No. PCT/JP99/07137 Filed: December 20, 1999

Japanese Patent Applns. No.: 10-365690

Japanese Patent Appln. Filing Date : December 22, 1998

For : Micro-machine Switch and Method of Fabricating the Same

VERIFICATION OF TRANSLATION

The Honorable Commissioner of Patents & Trademarks
Washington, DC 20231

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Date October 13, 2004 Signature H. Amano

Typed Name: HIROSHI AMANO

[Document Name] Patent Application

[File Reference] 34001868

[Filing Date] December 22, 1998

[Address] Commissioner, Patent Office

[International Patent Classification] H01H 36/00

[Title of the Invention] Micro-machine Switch and Method of fabricating the same

[Number of Claims] 36

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[Indication of Fee]

[Prepayment Ledger Number] 006194

[Amount of Payment] 21000

[List of Attachment]

[Name of Attachment] Specification 1

[Name of Attachment] Set of Drawings 1

[Name of Attachment] Abstract 1

[Number of General Power of Attorney] 9718363

[Document Name] Specification

[Title of the Invention] Micro-machine Switch and Method of fabricating the same

[Claims]

[Claim 1] A micro-machine switch electrically connecting a first signal line formed on a substrate to a second signal line or electrically disconnecting said first signal line from said second signal line, said second signal line being formed on said substrate and having an end spaced away from an end of said first signal line by a certain gap,

characterized by

a supporter formed on said substrate in the vicinity of said gap and having a predetermined height relative to a surface of said substrate,

a flexible beam projecting from said supporter in parallel with a surface of said substrate, and having a distal end facing said gap,

a contact electrode formed on a surface of said beam facing said substrate such that said contact electrode faces said gap,

a lower electrode formed on said substrate in facing relation with a part of said beam, and

an intermediate electrode formed on said beam in facing relation with said lower electrode.

[Claim 2] The micro-machine switch as set forth in claim 1, wherein said lower electrode is formed on said substrate between said supporter and said gap.

[Claim 3] The micro-machine switch as set forth in claim 1 or 2, wherein said supporter and at least a part of said beam are composed of the same electrically conductive material and are formed integrally with each other.

[Claim 4] The micro-machine switch as set forth in claim 1, 2 or 3, wherein said beam is comprised of an electrical conductor extending from said supporter and having such a length that said electrical conductor faces said lower electrode, and an electrical insulator extending from a distal end of said electrical conductor

and having such a length that said electrical insulator faces said gap,

said contact electrode being formed on said electrical insulator in facing relation with said gap.

[Claim 5] The micro-machine switch as set forth in claim 3 or 4, wherein said electrical conductor is composed of semiconductor.

[Claim 6] The micro-machine switch as set forth in claim 5, wherein said semiconductor is single crystal semiconductor.

[Claim 7] The micro-machine switch as set forth in claim 5, wherein said semiconductor is one of amorphous semiconductor and polycrystal semiconductor.

[Claim 8] The micro-machine switch as set forth in claim 1, wherein a surface of said supporter and a surface of said beam form an obtuse angle.

[Claim 9] The micro-machine switch as set forth in claim 1, wherein said beam includes a reinforcement formed at a side opposite to said contact electrode in alignment with said contact electrode.

[Claim 10] The micro-machine switch as set forth in claim 1, wherein said contact electrode is covered with an insulating film which makes connection with said first and second signal lines to form capacity.

[Claim 11] The micro-machine switch as set forth in claim 1, wherein said substrate is a glass substrate or a ceramic substrate.

[Claim 12] The micro-machine switch as set forth in claim 1, wherein said substrate is a gallium-arsenide substrate.

[Claim 13] The micro-machine switch as set forth in claim 1, wherein said intermediate electrode is electrically connected to said upper electrode, and said upper electrode is in an electrically floating condition.

[Claim 14] The micro-machine switch as set forth in claim 1, wherein said lower electrode is comprised of a plurality of electrodes each having the same area by which each of said electrodes faces said upper electrode.

[Claim 15] The micro-machine switch as set forth in claim 1, wherein said upper electrode is comprised of a plurality of electrodes each having the same

area by which each of said electrodes faces said lower electrode.

[Claim 16] The micro-machine switch as set forth in claim 1, wherein said lower electrode is comprised of a plurality of electrodes each having the same area by which each of said electrodes faces said upper electrode, and said upper electrode is comprised of a plurality of electrodes each having the same area by which each of said electrodes faces said lower electrode.

[Claim 17] The micro-machine switch as set forth in any one of claims 14 to 16, wherein each of said upper and lower electrodes comprised of a plurality of said electrodes defines a comb-shaped electrode.

[Claim 18] The micro-machine switch as set forth in claim 1, wherein said micro-machine switch is used in a phased-array antenna.

[Claim 19] A method of fabricating a micro-machine switch electrically connecting a first signal line formed on a substrate to a second signal line or electrically disconnecting said first signal line from said second signal line, said second signal line being formed on said substrate and having an end spaced away from an end of said first signal line by a certain gap, comprising the steps of:

fabricating a lower electrode on said substrate; and

adhering a block onto said substrate such that a later-mentioned contact electrode faces said gap and is spaced away from said first and second signal lines, said block including a supporter having a certain height, a flexible beam formed at said supporter, and a contact electrode formed at said beam.

[Claim 20] The method as set forth in claim 19, wherein said lower electrode is formed on said substrate between said supporter and said gap.

[Claim 21] The method as set forth in claim 19 or 20, wherein said supporter and said beam are composed of common electrically conductive material and are at least partially integrally formed with each other.

[Claim 22] The method as set forth in any one of claims 19 to 21, wherein said beam is composed of electrically conductive material from a portion at which said beam is connected to said supporter to a portion facing said lower electrode,

an electrically insulator extending so as to face said gap is formed at a distal end of said beam, and said contact electrode is disposed on said electrical insulator so as to face said gap.

[Claim 23] The method as set forth in claim 21 or 22, wherein said electrically conductive material is composed of semiconductor.

[Claim 24] The method as set forth in claim 23, wherein said semiconductor is monocrystal semiconductor.

[Claim 25] The method as set forth in claim 23, wherein said semiconductor is amorphous semiconductor or polycrystal semiconductor.

[Claim 26] The method as set forth in claim 19, wherein said supporter and said beam forms an obtuse angle therebetween.

[Claim 27] The method as set forth in claim 19, further comprising a reinforcement formed facing said electrical insulator at a side opposite to the contact electrode in alignment with the contact electrode.

[Claim 28] The method as set forth in claim 19, further comprising an electrically insulating film covering said contact electrode therewith, said electrically insulating film defining a capacity with said first and second signal lines.

[Claim 29] The method as set forth in claim 19, wherein said substrate is a glass or ceramic substrate.

[Claim 30] The method as set forth in claim 19, wherein said substrate is a gallium-arsenide substrate.

[Claim 31] The method as set forth in claim 19, wherein said intermediate electrode is electrically connected to said upper electrode, and said upper electrode is in an electrically floating condition.

[Claim 32] The method as set forth in claim 19, wherein said lower electrode is comprised of a plurality of electrodes each having the same area by which each of said electrodes faces said upper electrode.

[Claim 33] The method as set forth in claim 19, wherein said upper

electrode is comprised of a plurality of electrodes each having the same area by which each of said electrodes faces said lower electrode.

[Claim 34] The method as set forth in claim 19, wherein said lower electrode is comprised of a plurality of electrodes each having the same area by which each of said electrodes faces said upper electrode, and said upper electrode is comprised of a plurality of electrodes each having the same area by which each of said electrodes faces said lower electrode.

[Claim 35] The method as set forth in any one of claims 32 to 34, wherein each of said upper and lower electrodes comprised of a plurality of said electrodes defines a comb-shaped electrode.

[Claim 36] The method as set forth in claim 19, wherein said micro-machine switch is used in a phased-array antenna.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The invention relates to a micro-machine switch and a method of fabricating the same, and more particularly to a micro-machine switch which can conduct on-off control in a current ranging from a direct current (DC) to a current having a frequency of GHz or greater, and a method of fabricating the same.

[0002]

[Prior Art]

Prior art is explained hereinbelow with reference to "Micro-machine electric switch" invented by Yun Jayson Yao in Rockwell International Corporation (Japanese Patent Application Publication No. 9-17300).

[0003]

FIG. 18(a) is a plan view of the micro-machine switch suggested in Japanese Patent Application Publication No. 9-17300, and FIG. 18(b) is a longitudinal cross-sectional view taken along the line E-E' in FIG. 18(a). As illustrated in FIG. 18, an anchor structure 52 composed of thermosetting

polyimide, a lower electrode 53 composed of gold, and signal lines 54 composed of gold are formed on a substrate 51 composed of gallium-arsenide.

[0004]

A cantilever 55 composed of a silicon dioxide film is supported on the anchor structure 52. The cantilever 55 extends to the signal lines 54 beyond the lower electrode 53, and faces both the lower electrode 53 and the signal lines 54 with a spatial gap therebetween.

[0005]

An upper electrode 56 composed of aluminum is formed on an upper surface of the cantilever 55. The upper electrode 56 extends from the anchor structure 52 to a location at which the upper electrode 56 faces the lower electrode 53. A contact electrode 57 is formed on a lower surface of the cantilever 55 in facing relation with the signal lines 54.

[0006]

In the micro-machine switch having the above-mentioned structure, when a voltage of 30V is applied across the upper electrode 56 and the lower electrode 53, an electrostatic force is exerted on the upper electrode 56 as an attractive force towards the substrate 51 (downwardly along an arrow 58). As a result, the cantilever 55 is deformed towards the substrate 51, thereby the contact electrode 57 makes contact with the ends of the signal lines 54.

[0007]

In a normal condition, as illustrated in FIG. 19(b), there is a gap between the contact electrode 57 and the signal lines 54, and the signal lines 54 are spaced away from each other. Hence, in a condition in which a voltage is not applied to the lower electrode 53, a current does not run through the signal lines 54.

[0008]

In contrast, when a voltage is applied to the lower electrode 53, and resultingly, the contact electrode 57 makes contact with the signal lines 54, the

signal lines 54 make electrical contact with each other through the contact electrode 57. Thus, a current runs through the signal lines 54. Accordingly, by applying a voltage to the lower electrode 53, it is possible to cause a current to run through the signal lines 54, or carry out on/off control of a signal running through the signal lines 54.

[0009]

In order to reduce a loss in the switch, it is important to sufficiently electrically insulate the upper electrode 56 and the contact electrode 57 from each other. If the upper electrode 56 and the contact electrode 57 are electrically connected to each other, a signal (including a direct current) running through the signal lines 54 would run also through the upper electrode 56.

[0010]

Even if the upper electrode and the contact electrode 57 are not electrically connected to each other, an alternating current running through the signal lines 54 runs further through the upper electrode 56 under a circumstance where electrostatic capacity is so great.

As mentioned above, if the upper electrode 56 and the contact electrode 57 are not sufficiently electrically insulated from each other, a signal leaks out of the signal lines 54, resulting in deterioration in switch characteristics.

[0011]

[Problems to be solved]

However, it was found out that the above-mentioned conventional micro-machine switch is accompanied with the following problems.

It is necessary to apply a sufficient voltage across the upper electrode 56 and the lower electrode 53 such that a resultant electrostatic force overcomes a restoring force of the cantilever 55, in order to turn the switch on, namely, to cause the contact electrode 57 to make contact with the signal lines 54. Since the produced electrostatic force is in inverse proportion to a square of a distance between the upper electrode 56 and the lower electrode 53 (exactly, the distance

from which a thickness of the cantilever 55 is deducted), it is important to design the distance D as small as possible.

[0012]

In the conventional micro-machine switch, the distance D between the upper electrode 56 and the lower electrode 53 is greater by a thickness of the contact electrode 57 than a sum of a thickness of the cantilever 55 and a distance between the contact electrode 57 and the signal lines 54, as illustrated in FIG. 18(b). For instance, in order to reduce a loss in a signal in application of a micro-machine switch to a radio-frequency, it would be necessary to design the contact electrode 57 and the signal lines 54 to have a thickness of about 2 μm.

[0013]

It would be necessary to space the signal lines 54 and the contact electrode 57 from each other by 4 μm or greater, in order to reduce electrostatic capacity coupling between the signal lines 54 and the contact electrode 57 when the switch is off. Hence, the upper electrode 56 and the lower electrode 53 are spaced away from each other by a sum of a thickness of the cantilever 55 and 6 μm.

[0014]

It was found out by the inventors that a high voltage, specifically, a voltage of about 100V would be necessary, when an area in which the upper electrode 56 overlaps the lower electrode 53 is equal to 10,000 μm^2, and the cantilever 8 has a width of 20 μm and a length of 130 μm. Though it is possible to reduce a restoring force of the cantilever 8 by designing the cantilever 8 to have a greater length or a smaller width, such increasing a length or decreasing a width might cause breakage of the cantilever 8 during fabrication of a device or during operation of a device.

[0015]

On the other hand, it would be possible to generate a greater electrostatic force, and hence, reduce an applied voltage by increasing an area in

which the upper electrode 56 and the lower electrode 53 overlap each other. However, this causes an increase in a size of a device. In the conventional micro-machine switches, an applied voltage is reduced in accordance with the above-mentioned method. However, the above-mentioned method is accompanied with a problem that a device would have an increased size. Thus, there is a limit in the conventional methods to reduce a size of the micro-machine switch.

[0016]

In addition, since a high voltage, specifically, a voltage of about 100V is applied across the upper and lower electrodes, the cantilever 8 would be required to be composed of a qualified film, in order to prevent a device from being destroyed by dielectric breakdown. However, in the conventional method in which the cantilever 8 is formed of an oxide film on the contact electrode 57 composed of gold, by low-temperature deposition process (plasma-enhanced CVD process to be carried out at 250 degrees centigrade or smaller), it would be quite difficult to form such an oxide film having a sufficient resistance to a voltage.

[0017]

In addition, as an applied voltage becomes high, power consumption in a driver circuit increases. It was found out that the micro-machine switch could not be applied to an antenna having a plurality of switches, in particular.

[0018]

In view of the above-mentioned problems, it is an object of the present invention to provide a micro-machine switch operable at a lower voltage than an operational voltage of a conventional micro-machine switch, and a method of fabricating the same.

It is also an object of the present invention to improve device characteristics by enhancing a breakdown voltage of an insulating film, if it is not possible to lower an applied voltage.

[0019]

[Solution to the Problems]

In order to achieve the above-mentioned objects, in one aspect of the present invention, there is provided a micro-machine switch electrically connecting a first signal line formed on a substrate to a second signal line or electrically disconnecting the first signal line from the second signal line, the second signal line being formed on the substrate and having an end spaced away from an end of the first signal line by a certain gap, characterized by a supporter formed on the substrate in the vicinity of the gap and having a predetermined height relative to a surface of the substrate, a flexible beam projecting from the supporter in parallel with a surface of the substrate, and having a distal end facing the gap, a contact electrode formed on a surface of the beam facing the substrate such that the contact electrode faces the gap, a lower electrode formed on the substrate in facing relation with a part of the beam, and an intermediate electrode formed on the beam in facing relation with the lower electrode.

[0020]

In an embodiment of the micro-machine switch in accordance with the present invention, the lower electrode is formed on the substrate between the supporter and the gap.

In an embodiment of the micro-machine switch in accordance with the present invention, the supporter and at least a part of the beam are composed of the same electrically conductive material and are formed integrally with each other.

In an embodiment of the micro-machine switch in accordance with the present invention, the beam is comprised of an electrical conductor extending from the supporter and having such a length that the electrical conductor faces the lower electrode, and an electrical insulator extending from a distal end of the electrical conductor and having such a length that the electrical insulator faces the gap, the contact electrode being formed on the electrical insulator in facing relation with the gap.

[0021]

In an embodiment of the micro-machine switch in accordance with the present invention, the electrical conductor is composed of semiconductor.

In an embodiment of the micro-machine switch in accordance with the present invention, the semiconductor is single crystal semiconductor.

In an embodiment of the micro-machine switch in accordance with the present invention, the semiconductor is one of amorphous semiconductor and polycrystal semiconductor.

In an embodiment of the micro-machine switch in accordance with the present invention, a surface of the supporter and a surface of the beam form an obtuse angle.

In an embodiment of the micro-machine switch in accordance with the present invention, the beam includes a reinforcement formed at a side opposite to the contact electrode in alignment with the contact electrode.

[0022]

In an embodiment of the micro-machine switch in accordance with the present invention, the contact electrode is covered with an insulating film which makes connection with the first and second signal lines to form capacity.

In an embodiment of the micro-machine switch in accordance with the present invention, the substrate is a glass substrate or a ceramic substrate.

In an embodiment of the micro-machine switch in accordance with the present invention, the substrate is a gallium-arsenide substrate.

In an embodiment of the micro-machine switch in accordance with the present invention, the intermediate electrode is electrically connected to the upper electrode, and the upper electrode is in an electrically floating condition.

[0023]

In an embodiment of the micro-machine switch in accordance with the present invention, the lower electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the upper

electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, the upper electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the lower electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, the lower electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the upper electrode, and the upper electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the lower electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, each of the upper and lower electrodes comprised of a plurality of the electrodes defines a comb-shaped electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, the micro-machine switch is used in a phased-array antenna.

[0024]

In another aspect of the present invention, there is provided a method of fabricating a micro-machine switch electrically connecting a first signal line formed on a substrate to a second signal line or electrically disconnecting the first signal line from the second signal line, the second signal line being formed on the substrate and having an end spaced away from an end of the first signal line by a certain gap, including the steps of fabricating a lower electrode on the substrate; and adhering a block onto the substrate such that a later-mentioned contact electrode faces the gap and is spaced away from the first and second signal lines, the block including a supporter having a certain height, a flexible beam formed at the supporter, and a contact electrode formed at the beam.

[0025]

In an embodiment of the micro-machine switch in accordance with the present invention, the lower electrode is formed on the substrate between the

supporter and the gap.

In an embodiment of the micro-machine switch in accordance with the present invention, the supporter and the beam are composed of common electrically conductive material and are at least partially integrally formed with each other.

In an embodiment of the micro-machine switch in accordance with the present invention, the beam is composed of electrically conductive material from a portion at which the beam is connected to the supporter to a portion facing the lower electrode, an electrically insulator extending so as to face the gap is formed at a distal end of the beam, and the contact electrode is disposed on the electrical insulator so as to face the gap.

[0026]

In an embodiment of the micro-machine switch in accordance with the present invention, the electrically conductive material is composed of semiconductor.

In an embodiment of the micro-machine switch in accordance with the present invention, the semiconductor is monocrystal semiconductor.

In an embodiment of the micro-machine switch in accordance with the present invention, the semiconductor is amorphous semiconductor or polycrystal semiconductor.

In an embodiment of the micro-machine switch in accordance with the present invention, the supporter and the beam forms an obtuse angle therebetween.

[0027]

In an embodiment of the micro-machine switch in accordance with the present invention, the method further includes a reinforcement formed facing the electrical insulator at a side opposite to the contact electrode in alignment with the contact electrode.

In an embodiment of the micro-machine switch in accordance with the

present invention, the method further includes an electrically insulating film covering the contact electrode therewith, the electrically insulating film defining a capacity with the first and second signal lines.

In an embodiment of the micro-machine switch in accordance with the present invention, the substrate is a glass or ceramic substrate.

In an embodiment of the micro-machine switch in accordance with the present invention, the substrate is a gallium-arsenide substrate.

In an embodiment of the micro-machine switch in accordance with the present invention, the intermediate electrode is electrically connected to the upper electrode, and the upper electrode is in an electrically floating condition.

[0028]

In an embodiment of the micro-machine switch in accordance with the present invention, the lower electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the upper electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, the upper electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the lower electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, the lower electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the upper electrode, and the upper electrode is comprised of a plurality of electrodes each having the same area by which each of the electrodes faces the lower electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, each of the upper and lower electrodes comprised of a plurality of the electrodes defines a comb-shaped electrode.

In an embodiment of the micro-machine switch in accordance with the present invention, the micro-machine switch is used in a phased-array antenna.

[0029]

As mentioned above, the present invention lowers a voltage for driving a switch, by forming an intermediate electrode to thereby shorten a distance between an upper electrode and a lower electrode. For instance, it is assumed that an intermediate electrode having the same thickness as a thickness of a contact electrode is formed on an upper electrode with an insulating film being sandwiched therebetween, and that the intermediate electrode is not directly electrically connected to an external voltage circuit. When a voltage V is applied across the upper and lower electrodes, a voltage of the intermediate electrode is calculated in accordance with the following equation.

[0030]

$$V \cdot C_1 / (C_1 + C_2)$$

[0031]

C_1 indicates an electrostatic capacity between the intermediate and upper electrodes, and C_2 indicates an electrostatic capacity between the intermediate and lower electrodes. Since C_1 is greater than C_2, the intermediate and upper electrodes have almost the same voltage.

[0032]

Comparing the intermediate electrode to the conventional micro-machine switch, a distance between the intermediate and lower electrodes is equal to 4 μm, that is, a distance between the contact electrode and the signal lines. Namely, since a distance between the electrodes across which a voltage is applied is reduced down to 2/3 (= 4 μm/6 μm), a requisite voltage is also reduced down to about 67V (100 × 2/3). The present invention makes it possible to reduce an applied voltage down to 2/3 of a voltage required in the conventional micro-machine switch.

[0033]

In addition, since the intermediate electrode can be fabricated together with the contact electrode, the intermediate electrode can be fabricated without

any increase in fabrication costs of a device. As detailed in the later mentioned embodiments, the intermediate electrode may be designed to have various structures.

[0034]

As mentioned so far, the present invention makes it possible to operate a micro-machine switch at a voltage lower than a voltage at which a conventional micro-machine switch operates, and to enhance a breakdown voltage of an insulating film to thereby improve device performances.

[0035]

[Embodiments of the Invention]

Preferred embodiments in accordance with the present invention will be explained hereinbelow with reference to drawings.

[0036]

[First Embodiment]

FIG. 1(a) is a plan view of a micro-machine switch in accordance with the first embodiment of the present invention, and FIG. 1(b) is a cross-sectional view taken along the line A-A' in FIG. 1(a). As illustrated, a switch 14 composed of silicon, a lower electrode 4 composed of gold, and signal lines 3 composed of gold are formed on a glass substrate 1 having a high dielectric constant. An earth plate 2 is formed on a lower surface of the substrate 1.

[0037]

The switch 14 is comprised of a supporter 7, a cantilever 8, and an upper electrode 9, all of which are integral with one another. Two cantilevers 8 composed of silicon extend from the supporter 7 in parallel with a surface of the substrate. The two cantilevers 8 can reduce rotation thereof to thereby make it possible to prevent partial contact of a switch, in comparison with the single cantilever in the conventional micro-machine switch. The number of the cantilevers 8 is determined in accordance with conditions. The micro-machine switch may include one or two or more cantilevers 8.

[0038]

In the first embodiment, the supporter 7 and the cantilevers 8 are designed such that angles α and β formed by the supporter 7 and the cantilevers 8 at a connection of them make obtuse angles (90? $<\alpha$, $\beta<180°$). By setting the angles α and β to make obtuse angles, it would be possible to increase a strength of the cantilevers 8, and carry out switching to an alternating current having a frequency equal to or greater than 1 MHz.

[0039]

The upper electrode 9 composed of silicon is connected to the cantilevers 8 at distal ends of the cantilevers 8. The upper electrode 9 faces the lower electrode 4 with a spatial gap existing therebetween.

The supporter 7 is electrically connected to a signal line 3a formed on the substrate 1. The signal line 3a is electrically connected to the upper electrode 9 through the supporter 7 and the cantilevers 8.

[0040]

An electrical insulator 6 comprised of a silicon dioxide film, a silicon nitride film or other electrically insulating films is formed on a lower surface of the upper electrode 9, extending across the lower electrode 4 and the signal lines 3.

A contact electrode 5 composed of gold is formed on a lower surface of the electrical insulator 6 in facing relation with the signal lines 3. An intermediate electrode 15 is formed on the electrical insulator 6 in facing relation with the lower electrode 4.

[0041]

The electrical insulator 6 prevents the contact electrode 5 and the upper electrode 9 from short-circuited each other. The electrical insulator 6 may be formed only between the contact electrode 5 and the upper electrode 9 and between the intermediate electrode 15 and the upper electrode 9. When a radio-frequency signal is to be switched, it is preferable that the contact electrode

5 is covered with an electrically insulating film as long as the contact electrode 5 can make capacity coupling with the signal lines 3. As an alternative, the signal lines 3 may be covered with an electrically insulating film.

[0042]

As mentioned above, since the upper electrode 9 having a greater thickness than a thickness of the cantilever 8 is formed on the electrical insulator 6 facing the contact electrode 5, it would be possible to reduce curvature of the contact electrode 5 caused by a strain generated between the contact electrode 5 and the electrical insulator 6. Accordingly, the contact electrode 5 can keep parallel with the substrate 1, preventing an increase in a contact resistance caused by partial contact of the contact electrode 5.

[0043]

An operation of the first embodiment is explained hereinbelow.

When a voltage of 70V is applied across the upper electrode 9 and the lower electrode 4 through the signal line 3a, an electrostatic force is exerted on the upper electrode 9 as an attractive force downwardly towards the substrate 1. As a result, the cantilevers 8 are downwardly bent, and then, the contact electrode 5 makes contact with the signal lines 3.

[0044]

As illustrated in FIG. 1(a), a gap is formed between the signal lines 3 in alignment with the contact electrode 5. Thus, when a voltage is not applied, a current does not run through the signal lines 3. In contrast, when a voltage is applied across the upper electrode 9 and the lower electrode 4, and resultingly, the contact electrode 5 makes contact with the signal lines 3, a current runs through the signal lines 3. As mentioned above, it is possible to control on/off of a current running through the signal lines 3, by applying a voltage to the lower electrode 4. When a signal having a frequency of 30 GHz was switched by a conventional HEMT (High Electron Mobility Transistor) switch, an insertion loss was 3 to 4 dB, whereas when the same signal was switched by the micro-machine

switch in accordance with the first embodiment, an insertion loss was 2.5 dB.

[0045]

As mentioned above, in accordance with the first embodiment, since the upper electrode 9 is electrically connected to the supporter 7 composed of an electrically conductive material, through the cantilever 8 composed of an electrically conductive material, a voltage could be readily applied to the upper electrode 9. The upper electrode 9 may be designed to be electrically floating, in which case, it is no longer necessary to form the signal line 3a. What has to do in order to operate the micro-machine switch is just to apply a voltage to the lower electrode 4.

[0046]

The supporter 7, the cantilevers 8 and the upper electrode 9 may be composed of semiconductor material into which impurity is partially or entirely diffused, in which case, since quite a small current runs across the upper electrode 9 and the lower electrode 4 during an operation of the micro-machine switch, it would not be necessary to accurately control a content of impurity in semiconductor material.

[0047]

As explained in a later mentioned method of fabricating a micro-machine switch, the cantilever 8 could be readily formed to have a smaller thickness than thicknesses of other parts. By controlling a thickness of individual parts of the micro-machine switch, it would be possible to fabricate the cantilever 8 having flexibility, among parts having high stiffness. Accordingly, parts having high stiffness are deformed in a plane in parallel with the substrate 1 on application of a voltage, and almost all deformation is made in the thin cantilevers 8. This reduces partial contact of the contact electrode 5 with the signal lines 3.

[0048]

The upper electrode 9 may be designed to have a thickness equal to a

thickness of the cantilevers 8. By equalizing thicknesses of the upper electrode and the cantilevers to each other, a process of fabrication could be simplified.

[0049]

Table 1 shows typical dimensions of the parts constituting the micro-machine switch in accordance with the first embodiment.

[0050]

(Table 1)

	Width	Length	Thickness
Cantilever 8	10 μm	130 μm	3 μm
Upper electrode 9	100 μm	200 μm	10 μm
Contact electrode 5	70 μm	10 μm	2 μm
Intermediate electrode 15	90 μm	40 μm	2 μm

In Table 1, "width" means a length measured in a longitudinal direction in FIG. 1(a), "length" means a length measured in a transverse direction in FIG. 1(a), and "thickness" means a length measured in a longitudinal direction in FIG. 1(b). A distance between the intermediate electrode 15 and the lower electrode 4 is set equal to 4 μm.

[0051]

However, it should be noted that dimensions of the parts should be determined in accordance with specification of those parts, and are not to be limited to the above-mentioned dimensions. In accordance with the first embodiment, it would be possible to design a micro-machine switch in a wide range because of its enhanced designability. For instance, if the intermediate electrode 15 is designed to have a thickness slightly smaller than a thickness of the contact electrode 5, a contact force between the contact electrode 5 and the signal lines 3 would be increased, and a contact resistance between them would be decreased. This is in particular suitable to a switch turning on or off a DC signal.

[0052]

If the intermediate electrode 15 is designed to have a thickness slightly

greater than a thickness of the contact electrode 5, the contact electrode 5 would not make direct contact with the signal lines 3, even when the switch is on. When the micro-machine switch is to be applied to a radio-frequency signal, a signal can be transmitted through capacity contact in place of resistance contact. Hence, it is not always necessary for the contact electrode 5 to make direct contact with the signal lines 3. By designing the contact electrode 5 not to make direct contact with the signal lines 3, it would be possible to reduce mechanical abrasion of the contact electrode 5 and the signal lines 3, ensuring long lifetime of the micro-machine switch.

[0053]

The above-mentioned micro-machine switch is operated by applying a voltage across the supporter 7 electrically connected to the upper electrode 9 and the lower electrode 4, however, it should be noted that it is not always necessary to fix a voltage of the supporter 7. The micro-machine switch can be operated by applying a voltage only to the lower electrode 4. The supporter 7 (that is, the upper electrode 9) has not a fixed voltage, but a floating voltage, in which case, the upper electrode 9 would have a voltage influenced by surrounding voltages, and it would be possible to almost equalize a voltage of the supporter 7 to a ground voltage, by arranging ground lines around the supporter 7. Such ground lines are arranged generally in the vicinity of the switch 14.

When the supporter 7 is designed to have a floating potential, it would be not necessary to form a line to be electrically connected to the supporter 7, ensuring simplification in arrangement of lines in the micro-machine switch.

[0054]

Hereinbelow is explained a method of fabricating the micro-machine switch illustrated in FIG. 1.

FIGs. 2 and 3 are cross-sectional views illustrating respective steps of a method of fabricating the micro-machine switch illustrated in FIG. 1. Hereinbelow are explained steps in the method.

[0055]

First, as illustrated in FIG. 2(a), a pattern 12 composed of silicon dioxide is formed on a silicon substrate 11. Then, the silicon substrate 11 is etched by about 6 μ m through the use of tetramethylammonium hydroxide (TMAH) as an etchant.

When the substrate 11 is comprised of a silicon substrate having (100) plane as a principal plane, a trapezoidal projection is formed after etching due to dependency of an etching rate on plane azimuth. The trapezoidal projection has (111) plane as an exposed sidewall.

[0056]

Then, as illustrated in FIG. 2(b), a pattern 13 is newly formed on the substrate 1. Then, boron is diffused into non-masked area with the pattern 13 being used as a mask. Thereafter, the silicon substrate is thermally annealed, for instance, at 1150 degrees centigrade for 10 hours, in order to diffuse boron deeply. As a result, boron is diffused into the silicon substrate at a depth of about 10 μ m at a high concentration. Thus, there are formed the supporter 7 and the upper electrode 9.

[0057]

Then, as illustrated in FIG. 2(c), the pattern 13 is removed in an area corresponding to the cantilevers 8. Then, boron is diffused into the silicon substrate 11 in non-masked area with the rest of the pattern 13 being used as a mask. Thus, there is fabricated the switch 14 comprised of the supporter 7, the cantilevers 8 and the upper electrode 9.

The silicon substrate is thermally annealed, for instance, at 1150 degrees centigrade for 2 hours, in order to diffuse boron shallowly. As a result, boron is diffused into the silicon substrate at a depth of about 2 μ m at a high concentration.

[0058]

Then, as illustrated in FIG. 2(d), the electrical insulator 6 comprised of

a 1μm-thick silicon dioxide film and a 0.05μm-thick nitride film is formed so as to cover the upper electrode 9 therewith.

[0059]

Then, as illustrated in FIG. 3(e), the contact electrode 5 and the intermediate electrode 15 are formed on the electrical insulator 6 by gold plating.

[0060]

Then, as illustrated in FIG. 3(f), there is in advance fabricated a glass substrate 1 separately from the substrate 11. The lower electrode 4 composed of gold and the signal lines 3A, 3B and 3a all composed of gold are formed on the glass substrate 1. The substrate 11 is put on the glass substrate 1.

Thereafter, the supporter 7 is adhered to the glass substrate 1. The silicon and the glass may be adhered to each other by electrostatic coupling.

[0061]

Then, as illustrated in FIG. 3(g), the substrate 11 is dipped into an etching solution having a characteristic of selection to a boron concentration, such as ethylenediaminepyrocatechol, to thereby dissolve portions into which no boron is diffused. As a result, there is completed the micro-machine switch on the substrate 1.

[0062]

When the substrate 1 is composed of ceramics or gallium arsenide, the supporter may be adhered to the substrate 1 through an adhesive. As an alternative, the supporter 7 may be adhered to the substrate 1 by electrostatic coupling, if a glass layer having a thickness in the range of 2μm to 5μm is in advance formed on the substrate 1 by sputtering.

[0063]

As mentioned above, in the first embodiment, the switch 14 comprised of the cantilevers 8 and so on is formed by etching the single crystal silicon substrate. The first embodiment provides an advantage that the resultant could have highest reliability in its mechanical characteristic by composing the switch

of single crystal material.

[0064]

Since the cantilevers 8 are composed of single crystal material, curvature would not be generated due to a coefficient of thermal expansion, in comparison with the cantilever which is fabricated by layering a plurality of materials, in the conventional micro-machine switch. That is, since variation in a coefficient of thermal expansion of the cantilever 8 in a direction perpendicular to the substrate 1 at the side closer to the substrate is designed symmetrical with the same at the side remoter from the substrate, curvature in the cantilever 8 is suppressed.

[0065]

The micro-machine switch in accordance with the first embodiment may be fabricated in accordance with methods other than the above-mentioned one. For instance, a micro-machine switch having the same structure as that of the micro-machine switch in accordance with the first embodiment may be fabricated by forming a plurality of thin films on the substrate 1, and etching them in selected areas. The switch 14 may be composed of amorphous silicon, polysilicon or highly resistive semiconductor such as GaAs or InP into which iron is doped, in place of single crystal silicon. As an alternative, the switch 14 may be formed not of semiconductor, but of a metal such as gold or aluminum.

[0066]

[Second Embodiment]

A micro-machine switch in accordance with another embodiment is explained hereinbelow with reference to drawings.

FIG. 4(a) is a plan view of a micro-machine switch in accordance with the second embodiment of the present invention, and FIG. 4(b) is a cross-sectional view taken along the line B-B' in FIG. 4(a). As illustrated, a supporter 7 composed of silicon, a lower electrode 4 composed of gold, and signal lines 3 composed of gold are formed on a glass substrate 1 having a high

dielectric constant, in the micro-machine switch in accordance with the second embodiment. An earth plate 2 is formed on a lower surface of the substrate 1.

[0067]

The switch 14 is comprised of the supporter 7, a cantilever 8, and an upper electrode 9, all of which are integral with one another. Two cantilevers 8 composed of silicon extend from the supporter 7 in parallel with a surface of the substrate. The two cantilevers 8 can reduce rotation thereof to thereby make it possible to prevent partial contact of a switch, in comparison with the single cantilever in the conventional micro-machine switch. The number of the cantilevers 8 is determined in accordance with whole conditions, and the micro-machine switch may include one or two or more cantilevers 8.

[0068]

The supporter 7 and the cantilevers 8 are designed such that angles α and β formed by the supporter 7 and the cantilevers 8 at a connection of them make obtuse angles (90? $<\alpha$, $\beta<180°$). By setting the angles α and β to make obtuse angles, it would be possible to increase a strength of the cantilevers 8, and carry out switching to an alternating current having a frequency equal to or greater than 1 MHz.

[0069]

The upper electrode 9 composed of silicon is connected to the cantilevers 8 at distal ends of the cantilevers 8. The upper electrode 9 faces the lower electrode 4 with a spatial gap existing therebetween.

The supporter 7 is electrically connected to a signal line 3a formed on the substrate 1. The signal line 3a is electrically connected to the upper electrode 9 through the supporter 7 and the cantilevers 8.

[0070]

An electrical insulator 6 comprised of a silicon dioxide film, a silicon nitride film or other electrically insulating films is formed on a lower surface of the upper electrode 9, extending across the upper electrode 9 and the signal lines

3. A contact electrode 5 composed of gold is formed on a lower surface of the electrical insulator 6 in facing relation with the signal lines 3. An intermediate electrode 15 is formed on a lower surface of the electrical insulator 6 in facing relation with the lower electrode 4. When a radio-frequency signal is to be switched, the contact electrode 5 may be covered with an electrically insulating film as long as the contact electrode 5 can make capacity coupling with the signal lines 3. As an alternative, the signal lines 3 may be covered with an electrically insulating film.

[0071]

A reinforcement 10 composed of silicon is formed on the electrical insulator 6 in facing relation with the contact electrode 5. The reinforcement 10 reduces curvature of the electrical insulator 6 caused by a strain to be generated between the contact electrode 5 and the electrical insulator 6. The reinforcement 10 keeps the contact electrode 5 in parallel with the substrate 1, and hence, it is possible to prevent an increase in a contact resistance caused by a partial contact of the contact electrode 5 to the signal lines 3. It is not always necessary for the micro-machine switch to have the reinforcement 10 in dependence on a material of which the electrical insulator 6 is composed and/or a thickness of the electrical insulator 6. The invention may not include the reinforcement.

[0072]

An operation of the micro-machine switch in accordance with the second embodiment is explained hereinbelow.

When a voltage of 30V is applied across the upper electrode 9 and the lower electrode 4, an electrostatic force is exerted on the upper electrode 9 as an attractive force downwardly towards the substrate. As a result, the cantilevers 8 are downwardly bent, and then, the contact electrode 5 makes contact with the signal lines 3.

[0073]

As illustrated in FIG. 4(b), a gap is formed between the signal lines 3 in alignment with the contact electrode 5. Thus, when a voltage is not applied, a current does not run through the signal lines 3. In contrast, when a voltage is applied,. and resultingly, the contact electrode 5 makes contact with the signal lines 3, a current runs through the signal lines 3. As mentioned above, it is possible to control on/off of a current or signal running through the signal lines 3, by applying a voltage to the lower electrode 4. When a signal having a frequency of 30 GHz was switched by a conventional HEMT switch, an insertion loss was 3 to 4 dB, whereas when the same signal was switched by the micro-machine switch in accordance with the second embodiment, an insertion loss was 0.2 dB.

[0074]

As mentioned above, in accordance with the second embodiment, since the upper electrode 9 is electrically connected to the supporter 7 composed of an electrically conductive material, through the cantilever 8 composed of an electrically conductive material, a voltage could be readily applied to the upper electrode 9. The upper electrode 9 may be designed to be electrically floating, in which case, it is no longer necessary to form the signal line 3a. What has to do in order to operate the micro-machine switch is just to apply a voltage to the lower electrode 4.

[0075]

The supporter 7, the cantilever 8, the upper electrode 9 and the reinforcement 10 may be composed of semiconductor material into which impurity is partially or entirely diffused, in which case, since quite a small current runs across the upper electrode 9 and the lower electrode 4 during an operation of the micro-machine switch, it would not be necessary to accurately control a content of impurity in semiconductor material.

[0076]

As explained in a later mentioned method of fabricating a

micro-machine switch, the cantilever 8 could be readily formed to have a smaller thickness than thicknesses of other parts. By controlling a thickness of individual parts of the micro-machine switch, it would be possible to fabricate the cantilever 8 having flexibility, among parts having high stiffness.

Accordingly, parts having high stiffness are deformed in a plane in parallel with the substrate 1 on application of a voltage, and almost all deformation is made in the thin cantilevers 8. This reduces partial contact of the switch

[0077].

The upper electrode 9 may be designed to have a thickness equal to a thickness of the cantilevers 8. By equalizing thicknesses of the upper electrode and the cantilevers to each other, a process of fabricating the switch could be simplified.

[0078]

Table 2 shows typical dimensions of the parts constituting the micro-machine switch in accordance with the second embodiment.

[0079]

(Table 2)

	Width	Length	Thickness
Cantilever 8	10 μm	130 μm	3 μm
Upper electrode 9	100 μm	50 μm	10 μm
Contact electrode 5	70 μm	10 μm	2 μm
Intermediate electrode	90 μm	40 μm	2 μm

In Table 2, "width" means a length measured in a longitudinal direction in FIG. 4(a), "length" means a length measured in a transverse direction in FIG. 4(a), and "thickness" means a length measured in a longitudinal direction in FIG. 4(b). A distance between the intermediate electrode 15 and the lower electrode 4 is set equal to 4 μm.

[0080]

However, it should be noted that dimensions of the parts should be

determined in accordance with specification of those parts, and are not to be limited to the above-mentioned dimensions. In accordance with the second embodiment, it would be possible to design a micro-machine switch in a wide range because of its enhanced designability. For instance, if the intermediate electrode 15 is designed to have a thickness slightly smaller than a thickness of the contact electrode 5, a contact force between the contact electrode 5 and the signal lines 3 would be increased, and a contact resistance between them would be decreased. This is in particular suitable to a switch turning on or off a DC signal.

[0081]

If the intermediate electrode 15 is designed to have a thickness slightly greater than a thickness of the contact electrode 5, the contact electrode 5 would not make direct contact with the signal lines 3, even when the switch is on. When the micro-machine switch is to be applied to a radio-frequency signal, a signal can be transmitted through capacity contact in place of resistance contact. Hence, it is not always necessary for the contact electrode 5 to make direct contact with the signal lines 3. By designing the contact electrode 5 not to make direct contact with the signal lines 3, it would be possible to reduce mechanical abrasion of the contact electrode 5 and the signal lines 3, ensuring long lifetime of the micro-machine switch.

[0082]

The above-mentioned micro-machine switch is operated by applying a voltage across the supporter 7 electrically connected to the upper electrode 9 and the lower electrode 4, however, it should be noted that it is not always necessary to fix a voltage of the supporter 7. The micro-machine switch can be operated by applying a voltage only to the lower electrode 4. The supporter 7 (that is, the upper electrode 9) has not a fixed voltage, but a floating voltage, in which case, the upper electrode 9 would have a voltage influenced by surrounding voltages, and it would be possible to almost equalize a voltage of the supporter 7 to a

ground voltage, by arranging ground lines around the supporter 7. Such ground lines are arranged generally in the vicinity of the switch 14.

When the supporter 7 is designed to have a floating potential, it would be not necessary to form a line to be electrically connected to the supporter 7, ensuring simplification in arrangement of lines in the micro-machine switch.

[0083]

Hereinbelow is explained a method of fabricating the micro-machine switch illustrated in FIG. 4.

FIGs. 5 and 6 are cross-sectional views illustrating respective steps of a method of fabricating the micro-machine switch illustrated in FIG. 4. Hereinbelow are explained steps in the method.

[0084]

First, as illustrated in FIG. 5(a), a pattern 12 composed of silicon dioxide is formed on a silicon substrate 11. Then, the silicon substrate 11 is etched by about 6 μ m through the use of tetramethylammonium hydroxide (TMAH) as an etchant.

When the silicon substrate 11 is comprised of a silicon substrate having (100) plane as a principal plane, a trapezoidal projection is formed after etching due to dependency of an etching rate on plane azimuth. The trapezoidal projection has (111) plane as an exposed sidewall.

[0085]

Then, as illustrated in FIG. 5(b), a pattern 13 is newly formed on the substrate 1. Then, boron is diffused into non-masked area with the pattern 13 being used as a mask. Thereafter, the silicon substrate is thermally annealed, for instance, at 1150 degrees centigrade for 10 hours, in order to diffuse boron deeply. As a result, boron is diffused into the silicon substrate at a depth of about 10 μ m at a high concentration. Thus, there are formed the supporter 7, the upper electrode 9, and the reinforcement 10.

[0086]

Then, as illustrated in FIG. 5(c), the pattern 13 is removed in an area corresponding to the cantilevers. Then, boron is diffused into the silicon substrate 11 in non-masked area with the rest of the pattern 13 being used as a mask. Thus, there is fabricated the switch 14 comprised of the supporter 7, the cantilevers 8 and the upper electrode 9.

The silicon substrate is thermally annealed, for instance, at 1150 degrees centigrade for 2 hours, in order to diffuse boron shallowly. As a result, boron is diffused into the silicon substrate at a depth of about 2 μm at a high concentration.

[0087]

Then, as illustrated in FIG. 5(d), the electrical insulator 6 comprised of a 1 μm-thick silicon dioxide film and a 0.05 μm-thick nitride film is formed such that the electrical insulator 6 extends across the upper electrode 9 and the reinforcement 10.

[0088]

Then, as illustrated in FIG. 6(e), the contact electrode 5 and the intermediate electrode 15 are formed on the electrical insulator 6 by gold plating above the reinforcement 10.

[0089]

Then, as illustrated in FIG. 6(f), the thus fabricated substrate 11 is put on a glass substrate 1 on which the lower electrode 4 composed of gold and the signal lines 3 and 3a all composed of gold are formed. The glass substrate 1 is separately formed in accordance with steps other than the above-mentioned silicon process. Thereafter, the supporter 7 is adhered to the substrate 1. The silicon and the glass may be adhered to each other by electrostatic coupling.

[0090]

Then, as illustrated in FIG. 6(g), the substrate 11 is dipped into an etching solution having a characteristic of selection to a boron concentration, such as ethylenediaminepyrocatechol, to thereby dissolve portions into which no

boron is diffused. As a result, there is completed the micro-machine switch on the substrate 1.

[0091]

When the substrate 1 is composed of ceramics or gallium arsenide, the supporter 7 may be adhered to the substrate through an adhesive. As an alternative, the supporter 7 may be adhered to the substrate by electrostatic coupling, if a glass layer having a thickness in the range of 2μm to 5μm is in advance formed on the substrate 1 by sputtering.

[0092]

As mentioned above, in the second embodiment, the switch 14 comprised of the supporter 7 and so on is formed by etching the single crystal silicon substrate. The second embodiment provides an advantage that the resultant could have highest reliability in its mechanical characteristic by composing the switch of single crystal material.

[0093]

Since the cantilevers 8 are composed of single crystal material, curvature would not be generated due to a coefficient of thermal expansion, in comparison with the cantilever which is fabricated by layering a plurality of materials, in the conventional micro-machine switch. That is, since variation in a coefficient of thermal expansion of the cantilever 8 in a direction perpendicular to the substrate 1 at the side closer to the substrate is designed symmetrical with the same at the side remoter from the substrate, curvature in the cantilever 8 is suppressed.

[0094]

The micro-machine switch in accordance with the present invention may be fabricated in accordance with methods other than the above-mentioned one. For instance, a micro-machine switch having the same structure as that of the micro-machine switch in accordance with the first embodiment may be fabricated by forming a plurality of thin films on the substrate 1, and etching

them in selected areas. The switch 14 and the reinforcement 10 may be composed of amorphous silicon, polysilicon or highly resistive semiconductor such as GaAs or InP into which iron is doped, in place of single crystal silicon. As an alternative, the switch 14 and the reinforcement 10 may be formed not of semiconductor, but of a metal such as gold or aluminum.

[0095]

[Third Embodiment]

FIG. 7(a) is a plan view of a micro-machine switch in accordance with the third embodiment of the present invention, and FIG. 7(b) is a cross-sectional view. In FIG. 7, parts or elements that correspond to those illustrated in FIG. 4 have been provided with the same reference numerals.

[0096]

The micro-machine switch in accordance with the third embodiment is structurally different from the micro-machine switch in accordance with the second embodiment in that the electrical insulator 6b extends from a side surface of the upper electrode 9. The electrical insulator 6b may be composed of an oxide film, a nitride film or other electrically insulating thin films. As an alternative, the electrical insulator 6b may be composed of the same material as that of the upper electrode 9, in which case, the supporter 7, the cantilevers 8 and the upper electrode 9 may be composed of highly resistive semiconductor (GaAs or InP into which iron is doped), and impurities may be doped only into them for reducing a resistance thereof, or ions such as oxygen ions may be implanted into an area corresponding to the electrical insulator 6b to thereby increase a resistance thereof. Though the reinforcement 10 is formed in facing relation with the contact electrode 5 in the third embodiment, the present invention includes a micro-machine switch not having the reinforcement 10.

[0097]

The reinforcement 10 may be designed to have a high or low resistance. In the third embodiment, an electrical insulator 6a is formed on a bottom surface

of the upper electrode 9, separately from the electrical insulator 6b. The electrical insulator 6a prevents the upper electrode 9 and the lower electrode 4 from making contact with each other to thereby short-circuit with each other, when a voltage is applied across the upper electrode 9 and the lower electrode 4. It is preferable for the electrical insulator 6a to have a thickness smaller than a thickness of the contact electrode 5.

[0098]

Since the electrical insulator 6b in the third embodiment is located more highly above the substrate 1 in comparison with the first embodiment, it is possible to form a greater gap between the contact electrode 5 and the signal lines 3. This ensures a small electrostatic capacity and reduction in a leakage current when the micro-machine switch is off.

[0099]

In the above-mentioned embodiments, the substrate 1 is comprised of a glass substrate as a first example. A glass substrate is cheaper than a gallium-arsenide substrate, and is suitable to an application of the switch to a phased-array antenna on which a plurality of switches is requested to be integrated. However, the substrate 1 in the micro-machine switch in accordance with the present invention is not to be limited to a glass substrate, but may be comprised of a gallium-arsenide substrate, a silicon substrate, a ceramics substrate, a printing substrate or other substrates.

[0100]

By forming a through-hole or through-holes with the upper electrode 9, it would be possible to reduce squeeze effect caused by air existing between the upper electrode 9 and the lower electrode 4. By forming a through-hole or through-holes with the electrical insulator 6b, it would be possible to facilitate circulation of air to thereby reduce squeeze effect. In the present invention, a strength of the electrical insulator 6b could be readily reinforced by the upper electrode 9 and the reinforcement 10. Hence, even if the electrical insulator 6b

is formed with a plurality of through-holes, it would be possible for a movable part to have a sufficiently high stiffness.

In addition, by forming a through-hole or through-holes with the electrical insulator 6b, the contact electrode 5 and the reinforcement 10 to thereby facilitate air circulation therethrough, it would be possible to prevent squeeze effect.

[0101]

[Fourth Embodiment]

FIG. 8 is a cross-sectional view of a micro-machine switch in accordance with the fourth embodiment. In FIG. 8, parts or elements that correspond to those in the micro-machine switch in accordance with the first embodiment, illustrated in FIG. 1, have been provided with the same reference numerals. As illustrated in FIG. 8, the micro-machine switch in accordance with the fourth embodiment is designed to have two supporters 7 on the substrate 1 symmetrically around the signal lines 3. The upper electrode 9 is connected to the cantilevers 8 each extending from each of the supporters 7. Namely, the upper electrode 9 is supported at opposite ends thereof. In order to generate a sufficient electrostatic force, the micro-machine switch includes two lower electrodes 4 around the signal lines 3 below the upper electrode 9.

[0102]

As mentioned above, the present invention encompasses a structure in which the upper electrode 9 is supported by a plurality of supporters 7. The number of the supporters 7 may be two or more.

[0103]

[Fifth Embodiment]

FIG. 9 is a cross-sectional view of the micro-machine switch in accordance with the fifth embodiment of the present invention. In FIG. 9, parts or elements that correspond to those in the micro-machine switch in accordance with the first embodiment, illustrated in FIG. 1, have been provided with the

same reference numerals. In the micro-machine switch in accordance with the fifth embodiment, each of the cantilevers 8 is designed to be comprised of a silicon layer 8a and silicon dioxide layers 8b sandwiching the silicon layer 8a therebetween. The silicon dioxide layers are formed by oxidizing a surface of the switch 14 or other processes. By designing the silicon dioxide layers 8b to have the same thickness, a coefficient of thermal expansion in an area of the cantilevers 8 facing the substrate 1 is symmetrical with a coefficient of thermal expansion in an area of the cantilevers 8 at a side opposite to the substrate 1. This ensures prevention of curvature in the cantilevers 8 even if the cantilevers 8 are annealed at a high temperature.

[0104]

[Sixth Embodiment]

FIG. 10 is a cross-sectional view of the micro-machine switch in accordance with the sixth embodiment of the present invention. In FIG. 10, parts or elements that correspond to those in the micro-machine switch in accordance with the first embodiment, illustrated in FIG. 9, have been provided with the same reference numerals. As illustrated in FIG. 10, each of the cantilevers 8 in the sixth embodiment is designed to have a superlattice structure in which films composed of two or more different materials are alternately stacked one on another. Similarly to the fifth embodiment, the sixth embodiment ensures that a coefficient of thermal expansion in an area of the cantilevers 8 facing the substrate 1 is symmetrical with a coefficient of thermal expansion in an area of the cantilevers 8 at a side opposite to the substrate 1. Thus, it is possible to prevent curvature in the cantilevers 8 caused by variation in temperature.

[0105]

[Seventh Embodiment]

FIG. 11(a) is a plan view of a micro-machine switch in accordance with the seventh embodiment of the present invention, and FIG. 14(b) is a

cross-sectional view taken along the line D-D' in FIG. 13(a). In FIG. 11, parts or elements that correspond to those in the micro-machine switch illustrated in FIG. 4, have been provided with the same reference numerals. As illustrated in FIG. 11, the seventh embodiment is structurally different from the second embodiment in that the intermediate electrode 11 is electrically connected to the upper electrode 4 through a wire 18 filled in a through-hole formed through the electrical insulator 6, and that the intermediate electrode 15 and the contact electrode 5 are covered with electrically insulating films 16 and 17, respectively.

[0106]

Since the intermediate electrode 15 is electrically connected to the upper electrode 9, the intermediate electrode 15 has the same potential as that of the upper electrode 9. The electrically insulating film 16 covering the intermediate electrode 15 prevents the intermediate electrode 15 and the lower electrode 4 from short-circuiting each other. The electrically insulating film 17 covering the contact electrode 5 is formed in symmetry with the electrically insulating film 16 in order to make contact with the signal lines 3, when the electrically insulating film 16 makes contact with the lower electrode 3.

[0107]

The intermediate electrode 15 may be electrically connected to the upper electrode 9 through a wire formed at an end of the electrical insulator 6, in place of the wire 18 embedded in the electrical insulator 16. The electrical insulator 6 to be formed between the intermediate electrode 15 and the upper electrode 9 may be omitted.

[0108]

The lower electrode 4 and the signal lines 3 may be partially covered with the electrically insulating films 16 and 17. A switch for turning a DC signal on or off can be fabricated by omitting the electrically insulating film 17 covering the contact electrode 5 therewith, and designing a sum of thicknesses of the intermediate electrode 15 and the electrically insulating film 16 to be smaller

than a thickness of the contact electrode 5.

[0109]

It is possible to prevent the intermediate electrode 15 and the lower electrode 4 from short-circuiting each other also by omitting the electrically insulating film 16, and designing a thickness of the intermediate electrode 15 to be smaller than either a thickness of the contact electrode 5 or a sum of thicknesses of the contact electrode 5 and the electrically insulating film 17. The electrically insulating film 16 may be formed covering both the intermediate electrode 15 and the lower electrode 4 therewith. Similarly, the electrically insulating film 17 may be formed covering both the contact electrode 5 and the signal lines 3 therewith. It is not always necessary for the electrically insulating films 16 and 17 to entirely cover the intermediate electrode 15 and the contact electrode 5 therewith, respectively. The electrically insulating films 16 and 17 may be designed to partially cover intermediate electrode 15 and the contact electrode 5 therewith, respectively.

[0110]

[Eighth Embodiment]

FIG. 12 is a plan view of a micro-machine switch in accordance with the eighth embodiment of the present invention. In FIG. 12, parts or elements that correspond to those in the micro-machine switch in accordance with the first embodiment, illustrated in FIG. 1, have been provided with the same reference numerals. As illustrated in FIG. 12, the micro-machine switch in accordance with the eighth embodiment is structurally different from the second embodiment in that the lower electrode is comprised of two lower electrodes 4a and 4b such that the lower electrode could have two electrically different potentials below the intermediate electrode 15.

[0111]

In the micro-machine switch in accordance with the eighth embodiment, a voltage is applied to both the lower electrodes 4a and 4b, and the

supporter 7 connected to the upper electrode 9 is electrically floating. A half of the voltage applied across the two lower electrodes 40a and 40b is exerted between the lower electrodes 4a and 4b, and the intermediate electrode 15.

[0112]

Thus, since a voltage causing an electrostatic attractive force for closing the switch is reduced down to a half, the switch can be closed by applying a voltage twice greater than the voltage applied in the second embodiment. Since the upper electrode 9 is in an electrically floating condition, there is not caused a problem that the electrical insulator 6 located between the upper electrode 9 and the lower electrodes 4a and 4b are destroyed because of a high voltage. Above all, since it is not necessary to form the signal line 3a through which a voltage is applied to the supporter 7, there is provided an advantage that wire arrangement in the device can be simplified.

[0113]

Though a method of operating a micro-machine switch with the supporter 7 being kept in an electrically floating condition, having been explained in the first embodiment, may be accompanied with a problem that the micro-machine switch is influenced by surrounding wires (for instance, when a plurality of micro-machines are arranged, voltages for driving the micro-machines may be different from one another), a micro-machine switch can be operated without being influenced by surroundings in accordance with the present embodiment.

[0114]

Though the upper electrode 9 is connected to the cantilevers 8 in the present embodiment, the upper electrode 9 may be omitted, because a potential of the intermediate electrode 15 can be determined based on the two lower electrodes 4a and 4b. The upper electrode 9 may be used as a reinforcement. The upper electrode 9 may be separated from the cantilevers 8. The supporter 7, the cantilevers 8 and the upper electrode 9 may be composed of an electrically

insulating material or a highly resistive semiconductor material.

[0115]

[Ninth Embodiment]

FIG. 13 is a plan view of a micro-machine switch in accordance with the ninth embodiment of the present invention. In FIG. 13, parts or elements that correspond to those in the micro-machine switch illustrated in FIG. 12, have been provided with the same reference numerals.

As illustrated in FIG. 13, the ninth embodiment is structurally different from the eighth embodiment in that the lower electrode is comprised of two comb-shaped lower electrodes 4c and 4d such that the lower electrode could have two electrically different potentials below the intermediate electrode 15.

[0116]

In the eighth embodiment, the lower electrodes 4a and 4b have to be arranged symmetrically around a center of the upper electrode 9, when the switch 14 is adhered to the substrate 1. That is, unless an area in which the intermediate electrode 15 overlaps the lower electrode 4a is equal in size to an area in which the intermediate electrode 15 overlaps the lower electrode 4b, a potential of the intermediate electrode 15 does not become equal to a half of a voltage applied to the lower electrodes 4a and 4b, and resultingly, the upper electrode 9 may be attracted to a lower electrode having a larger area. As a result, the cantilevers 8 are twisted.

[0117]

In order to solve such a problem, the lower electrodes are designed to have a comb-shaped structure in the present embodiment. The comb-shaped structure ensures that an area in which the upper electrode overlaps the lower electrode is equal in size to an area in which the upper electrode overlaps the lower electrode, even if the switch 14 is adhered to the substrate in deviation. The number of combs is not to be limited to the illustrated case. The lower electrodes may have three or more combs. The combs may be designed to extend

in any direction. In the embodiments illustrated in FIGs. 12 and 13, separation of an electrode is not to be limited to the lower electrode. The upper electrode may be electrically separated into two or more electrodes. As an alternative, both the upper and lower electrodes may be separated into a plurality of electrodes. The number of electrodes into which the upper and/or lower electrodes are(is) separated is not to be limited to two, and may be three or four or greater.

[0118]

[Tenth Embodiment]

Hereinbelow is explained an application of the micro-machine switches in accordance with the above-mentioned first to ninth embodiments to a phase-array antenna.

As explained below, the above-mentioned micro-machine switches can be used for switching a signal in the range of a direct current signal to an alternating current having a high frequency, and in particular, and is suitable to a phased-array antenna.

[0119]

FIG. 14 is a block diagram of a phase-array antenna suggested in Japanese Patent Application No. 10-176367. The illustrated phased-array antenna includes M antennas 23 (M is an integer equal to or greater than 2), which are electrically connected to a phase-shifting circuit 24. The phase-shifting circuit 24 is comprised of a data distributing circuit 24a, M data latching circuits 24b electrically connected to the data distributing circuit 24a, and phase shifters 24c each electrically connected to the data latching circuits 24b.

[0120]

Each of the antennas 23 is electrically connected to an associated N-bit (N is a natural integer) phase shifter 24c, and the phase shifters 24c are electrically connected to a power feeder 21 through a distributor and synthesizer

22.

[0121]

The data distributing circuit 24a is electrically connected to a controller 20. The data distributing circuit 24a and the data latching circuits 24b are formed as a thin film transistor circuit (TFT circuit) on a substrate.

[0122]

Each of the phase shifters 24c is designed to include one of the above-mentioned micro-machine switch for each of bits. Each of the data latching circuits 24b is electrically connected to a micro-machine switch in the associated phase shifters 24c. In the phased-array antenna illustrated in FIG. 14, a circuit for driving phase shifters, which has been conventionally formed as an externally additional IC, is comprised of the TFT circuit, and is formed in the same layer as the phase shifters 24c.

[0123]

Hereinbelow is explained an operation of the phased-array antenna illustrated in FIG. 14. The controller 20 calculates a degree of phase-shifting optimal for directing radiated beams to a desired direction, with an accuracy of N bits, based on predetermined locations of the antennas 23 and frequencies selected in the antennas 23. The calculation results are output to the data distributing circuit 24a as a control signal. The data distributing circuit 24a distributes the control signal to the data latching circuits 24b.

[0124]

Directions in which radio waves are directed from the antennas 23 are simultaneously switched in all the antennas 23. In this end, the data latching circuits 24b rewrite data stored therein into a control signal as input data in synchronization with a timing signal by which a direction in which a beam is radiated is switched, and apply a drive voltage at a time to the micro-machine switches in a bit selected by the phase shifters 24c, based on the stored data (a control signal).

[0125]

On application of a drive voltage to the micro-machine switch, the micro-machine switch is closed, and resultingly, a bit including the micro-machine switch is turned on. A degree of phase shifting in the phase shifter 24c is determined in accordance with bits turned on in the phase shifter 24c.

[0126]

Each of the phase shifters 24c varies a phase of a radio-frequency signal by the thus determined degree of phase shifting, and supplies electric power to the antennas 23. Each of the antennas 23 makes radiation in a phase determined in accordance with the supplied phase. The radiation defines an equiphase plane. Beams are radiated in a direction perpendicular to the equiphase plane.

[0127]

Hereinbelow is explained a structure of the phased-array antenna illustrated in FIG. 14.

FIG. 15 is an exploded perspective view of the phased-array antenna. As illustrated, the phased-array antenna has a multi-layered structure. Specifically, the phased-array antenna is comprised of a distribution and synthesis layer L1, a dielectric substance layer L2, a slot layer L3 used for power feeding, a dielectric substance layer L4, a layer L5 including a radiator, a phase shifter, and a TFT circuit (hereinbelow, a layer L5 is referred to as "a phase-shifting circuit layer"), a dielectric substance layer L6, and a parasitic device layer L7. The layers are closely adhered to one another.

[0128]

The layers make a multi-layered structure by either photolithography and etching or adhesion process. For instance, the parasitic device layer L7 and the phase-shifting circuit layer L5 are formed by carrying out photolithography and etching to a metal film formed on opposite surfaces of the dielectric

substance layer L6. The slot layer L3 is formed by carrying out photolithography and etching to a metal film formed on a surface of the dielectric substance layer L4.

[0129]

A plurality of parasitic devices 32 is arranged on the parasitic device layer L7. The parasitic devices 32 enlarge an antenna band, and electromagnetically coupled to radiators 31 formed in the phase-shifting circuit layer L5, through the dielectric substance layer L6. The dielectric substance layer L6 is composed of a dielectric substance having a dielectric constant in the range of about 2 to about 10. For instance, fabrication costs could be reduced by using glass as a dielectric substance. Hence, it is preferable that at least one of the dielectric substance layers is a glass layer. If fabrication costs are ignored, the dielectric substance layer L6 may be composed of a dielectric substance such as alumina having a high dielectric constant or foaming material having a low dielectric constant.

[0130]

On the phase-shifting circuit layer L5 are formed a part of the antennas 23 illustrated in FIG. 12, the phase-shifting circuit 24, and strip lines through which power is fed to the antennas 23.

[0131]

The dielectric substance layer L4 is composed of a dielectric substance having a dielectric constant in the range of about 3 to about 12, such as alumina.

The slot layer L3 is composed of electrically conductive metal, and is formed with a plurality of slots 30 through which power is to be fed. The slot layer L3 is electrically connected to the phase-shifting circuit layer L5 through through-holes formed through the dielectric substance layer L4, and acts as a ground for the phase-shifting circuit layer L5.

[0132]

A plurality of distributor and synthesizers 22 are formed on the

distribution and synthesis layer L1. The distributor and synthesizers 22 are electromagnetically connected to the phase-shifting circuit layer L5 through the slots 30 formed through the slot layer L3. Each of the distributor and synthesizers 22 and each of the slots 30 define one power feeding unit, and the power feeding units are arranged in a matrix. The present invention encompasses a phase-array antenna including power feeding units arranged in a non-matrix.

[0133]

The radiators 32 may be arranged in a matrix or two-dimensionally. As an alternative, the radiators may be arranged in a line in a direction. In FIG. 15, the distributor 22 and the phase-shifting circuit layer L5 are electromagnetically coupled to each other through the slot layer L3. However, the distributor 22 and the phase-shifting circuit layer L5 may be formed in a common plane, if the distributor 22 and the phase-shifting circuit layer L5 are connected to each other through a power feeding coupler such as a power feeding pin.

[0134]

Hereinbelow is explained the phase-shifting circuit layer L5 illustrated in FIG. 15. FIG. 16 is a plan view illustrating the phase-shifting circuit layer L5 in one unit. As illustrated, a radiator 41, a group of phase shifters 40, and data latching circuits 46 are formed on the dielectric substance layer L6 comprised of a glass substrate or other materials. Each of the data latching circuits 46 is formed for each bits of the phase shifters 40a, 40b, 40c and 40d.

[0135]

A strip line 42 extends from the radiator 41 to a location which is in alignment with the slot 30 illustrated in FIG. 15, through the phase shifters 40. The radiator 41 may be comprised of a patch antenna, a printed dipole, a slot antenna, or an aperture device. The strip line 42 may be comprised of a distributed constant line such as a micro-strip line, a triplet line, a coplanar line,

or a slot line.

[0136]

The phase shifters 40 illustrated in FIG. 16 include four phase shifters 40a, 40b, 40c and 40d, and define a 4-bit phase shifter. Each of the phase shifters 40a, 40b, 40c and 40d can vary a phase in fed power by 22.5 degrees, 45 degrees, 90 degrees, and 180 degrees, respectively, and is comprised of a strip line and a micro-machine switch.

[0137]

Each of the phase shifters 40a, 40b and 40c is comprised of two strip lines 44 electrically connected between the strip line 42 and the ground 43, and a micro-machine switch 45 incorporated in the strip line 44. The phase shifters define a loaded line type phase shifter.

[0138]

The phase shifter 40d is comprised of a micro-machine switch 45a incorporated in the strip line 42, a U-shaped strip line 44a, and a micro-machine switch 45b electrically connected between the strip line 44a and the ground 43. The phase shifter defines a switched line type phase shifter.

[0139]

The loaded line type phase shifter would have better characteristics for a small degree of phase shifting, whereas the switched line type phase shifter would have better characteristic for a great degree of phase-shifting. Hence, in the present embodiment, the loaded line type phase shifters are used as 22.5-degrees, 45-degrees and 90-degrees phase shifters, respectively, as mentioned earlier, and the switched line type phase shifter 40d is used as a 180-degrees phase shifter. The switched line type phase shifters may be used as the phase shifters 40a, 40b and 40c.

[0140]

The two micro-machine switches (45a and 45b) included in each of the phase shifters 40a, 40b, 40c and 40d are electrically connected to a data latching

circuit 46 positioned in the vicinity thereof, and are simultaneously operated by a drive voltage output from the data latching circuit 46.

As mentioned above, a radio-frequency signal running through the strip line 42 has a phase varied in accordance with an operation of the phase shifters 40.

[0141]

In place of positioning the data latching circuit 46 in the vicinity of micro-machine switches, a plurality of the data latching circuits may be arranged at a certain site, and electrically connected to the micro-machine switches for driving the micro-machine switches 45, 45a, and 45b. As an alternative, one data latching circuit may be electrically connected to the micro-machine switched each in one of units different from one another.

[0142]

FIG. 17 is an enlarged plan view of a periphery of the micro-machine switch 45 used in the loaded line type phase shifter.

As illustrated, the two micro-machine switched 45 are arranged in symmetry with each other around the two strip lines 44. The micro-machine switches 45 are electrically connected to a data latching circuit (not illustrated), and are concurrently supplied a drive voltage (an external voltage) from the data latching circuit. The micro-machine switch 45 may be comprised of any one of the micro-machine switch in accordance with the first to seventh embodiments.

[0143]

[Advantages provided by the Invention]

As having been explained so far, the intermediate electrode is formed between the lower electrode and the upper electrode in the micro-machine switch in accordance with the present invention. The intermediate electrode reduces a voltage applied for driving a switch.

For instance, if a gap of 4 μm is formed between the contact electrode and the signal lines, a voltage to be applied across the upper and lower electrodes

can be reduced down to about 2/3 of a voltage to be applied in the conventional micro-machine switch. If a distance between the contact electrode and the signal lines is set equal to or smaller than 4μm, it would be possible to further reduce a voltage to be applied across the upper and lower electrodes. Specifically, the voltage can be reduced down to about 2/3 or smaller of a voltage to be applied in the conventional micro-machine switch.

[0144]

Since the intermediate electrode can be formed simultaneously with the conventional contact electrode, it would be not necessary to add extra steps to a method of fabricating the micro-machine switch in accordance with the invention, preventing an increase in fabrication costs. In addition, since a voltage to be applied can be reduced, as mentioned earlier, it would be possible to prevent a high voltage from being applied to the electrically insulating film formed between the upper and lower electrodes. This makes it no longer necessary to form a qualified electrically insulating film, widening selection in processes of fabricating the micro-machine switch. Accordingly, it would be possible to prevent destruction of the switch caused by limitation in a breakdown voltage in the electrically insulating film. A voltage required for driving an external driver circuit can be also reduced, ensuring simplification of the external driver circuit and reduction in power consumption.

[0145]

When the lower electrode is divided into two electrodes, a higher voltage would have to be applied to the lower electrode, in comparison with one lower electrode having an area equal to a total of areas of the divided electrodes. However, since a voltage is not applied to the electrically insulating film in the divided electrodes, it would be possible to prevent occurrence of dielectric breakdown, even if the electrically insulating film had a poor quality. An increase in an applied voltage can be compensated for by an increase in a size of the switch. Hence, the lower electrode can be divided into two or more

electrodes, if it is not always necessary to reduce a size of the micro-machine switch. Above all, since it is no longer necessary for the micro-machine switch to have an upper electrode and the micro-machine switch can be operated merely by applying a voltage to the lower electrode, there is obtained an advantage that wire arrangement in the micro-machine switch can be simplified. Hence, it is possible to significantly improve shortcomings such as an increase in fabrication costs due to complicated wire arrangement, a complicated structure of the switch and reduction in long-term reliability.

[0146]

Since the method of fabricating a micro-machine switch, in accordance with the present invention, can be carried out at a high temperature, following advantages are obtained.

1) A material of which the beam is composed can be selected from a wide range of materials. Various electrical conductors and semiconductors can be selected. Thus, designability in selecting materials is enhanced.

2) Since the electrically insulating film fabricated at a high temperature has a high breakdown voltage, the resultant micro-machine switch could have enhanced electrical characteristics.

3) Since designability in a thickness-wise direction is enhanced, it would be possible to reduce a width of the beam, ensuring reduction in a size of the micro-machine switch.

[0147]

By virtue of the above-mentioned advantages, the micro-machine switch in accordance with the present invention can be applied not only to an individually used conventional switch, but also to a phased-array antenna which is required to integrate switches on a wide-area substrate in an order to ten thousands.

[Brief Description of Drawings]

[FIG. 1] FIG. 1(a) is a plan view of a micro-machine switch in

accordance with the first embodiment of the present invention, and FIG. 1(b) is a cross-sectional view taken along the line A-A' in FIG. 1(a).

[FIG. 2] FIG. 2 includes cross-sectional views showing respective steps of a method of fabricating the micro-machine switch illustrated in FIG. 1.

[FIG. 3] FIG. 3 includes cross-sectional views showing respective steps following the steps illustrated in FIG. 2.

[FIG. 4] FIG. 4(a) is a plan view of a micro-machine switch in accordance with the second embodiment of the present invention, and FIG. 4(b) is a cross-sectional view taken along the line B-B' in FIG. 4(a).

[FIG. 5] FIG. 5 includes cross-sectional views showing respective steps of a method of fabricating the micro-machine switch illustrated in FIG. 4.

[FIG. 6] FIG. 6 includes cross-sectional views showing respective steps following the steps illustrated in FIG. 5.

[FIG. 7] FIG. 7(a) is a plan view of a micro-machine switch in accordance with the third embodiment of the present invention, and FIG. 7(b) is a cross-sectional view taken along the line C-C' in FIG. 7(a).

[FIG. 8] FIG. 8 is a cross-sectional view of a micro-machine switch in accordance with the fourth embodiment of the present invention.

[FIG. 9] FIG. 9 is a cross-sectional view of a micro-machine switch in accordance with the fifth embodiment of the present invention.

[FIG. 10] FIG. 10 is a cross-sectional view of a micro-machine switch in accordance with the sixth embodiment of the present invention.

[FIG. 11] FIG. 11(a) is a plan view of a micro-machine switch in accordance with the seventh embodiment of the present invention, and FIG. 11(b) is a cross-sectional view taken along the line D-D' in FIG. 11(a).

[FIG. 12] FIG. 12 is a plan view of a micro-machine switch in accordance with the eighth embodiment of the present invention.

[FIG. 13] FIG. 13 is a plan view of a micro-machine switch in accordance with the ninth embodiment of the present invention.

[FIG. 14] FIG. 14 is a block diagram of a phased-array antenna (the tenth embodiment of the present invention).

[FIG. 15] FIG. 15 is an exploded perspective view illustrating a structure of the phased-array antenna illustrated in FIG. 14.

[FIG. 16] FIG. 16 is a plan view of a phase-shifting circuit illustrated in FIG. 15.

[FIG. 17] FIG. 17 is a plan view illustrating a periphery of a micro-machine switch illustrated in FIG. 16.

[FIG. 18] FIG. 18(a) is a plan view of a conventional micro-machine switch, and FIG. 18(b) is a cross-sectional view taken along the line E-E' in FIG. 18(a).

[Indication by Reference Numerals]

1 Substrate　2 Earth plate　3, 3a Signal lines

4, 4a, 4b, 4c, 4d Lower electrodes　5 Contact electrode

6, 6a, 6b Electrical insulators　7 Supporter

8 Cantilever　8a Silicon layer　8b Silicon oxide layer

9 Upper electrode　10 Reinforcement　11 Substrate

12, 13 Pattern　14 Switch　15 Intermediate electrode

16, 17 Electrically insulating films　18 Wire

20 Controller　21 Power feeder　22 Distributor and synthesizer

23 Antenna　24 Phase-shifting circuit

24a Data distributing circuit　24b Data-latching circuit

24c Phase shifter　30 Slot　31 Phase-shifting circuit

32 Parasitic device　40 Phase shifter group

40a, 40b, 40c, 40d Phase shifters　41 Radiator

42 Strip line　43 Ground　44, 44a Strip lines

45, 45a Micro-machine switches　46 Data-latching circuit

L1 Synthesis layer　L2, L4, L6 Dielectric substance layers

L3 Slot layer　L5 Phase-shifting circuit layer　L7 Parasitic device layer

[Document] Abstract

[Abstract]

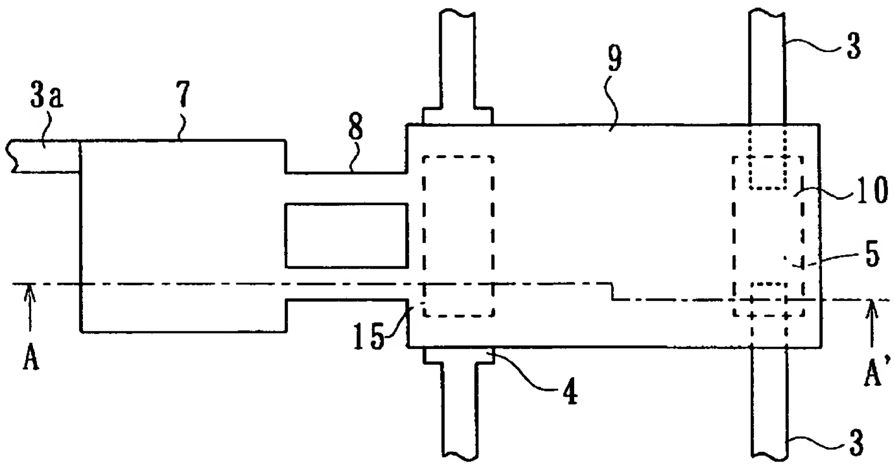
[Purpose] To design a micro-machine switch to be able to operate with a voltage lower than a voltage with which a convention micro-machine switch is operated, and to increase a resistance to voltage in an electrically insulating film.

[Solution] The micro-machine switch includes a supporter 7 formed on a substrate 1 in the vicinity of a gap of signal lines 3 and having a predetermined height relative to a surface of the substrate 1, a flexible beam (cantilever) 8 projecting from the supporter 7 in parallel with a surface of the substrate 1, and having a portion facing the gap, a contact electrode 5 formed on a surface of the beam facing the substrate such that the contact electrode faces the gap, a lower electrode 4 formed on the substrate 1 in facing relation with a part of the beam, and an intermediate electrode 15 formed on the beam in facing relation with the lower electrode 4.

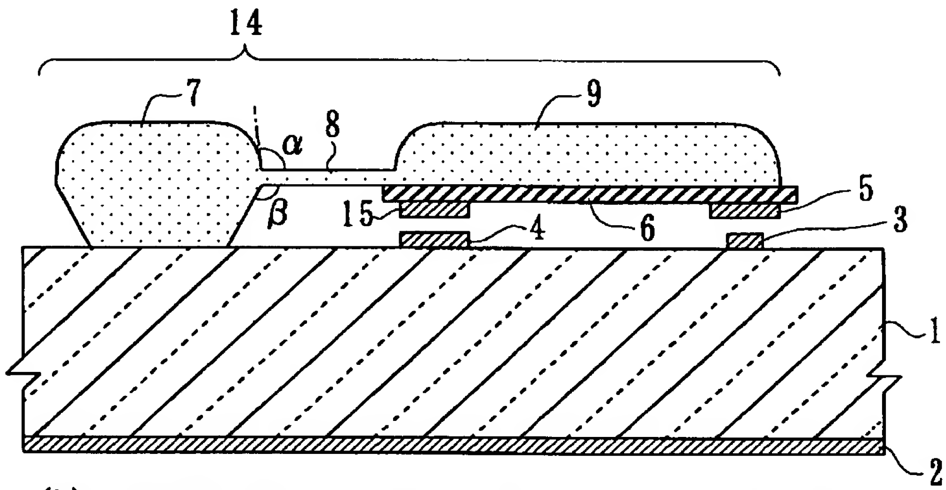
[Representative drawing] FIG. 1

【Document Name】 Drawings

【Fig.1】

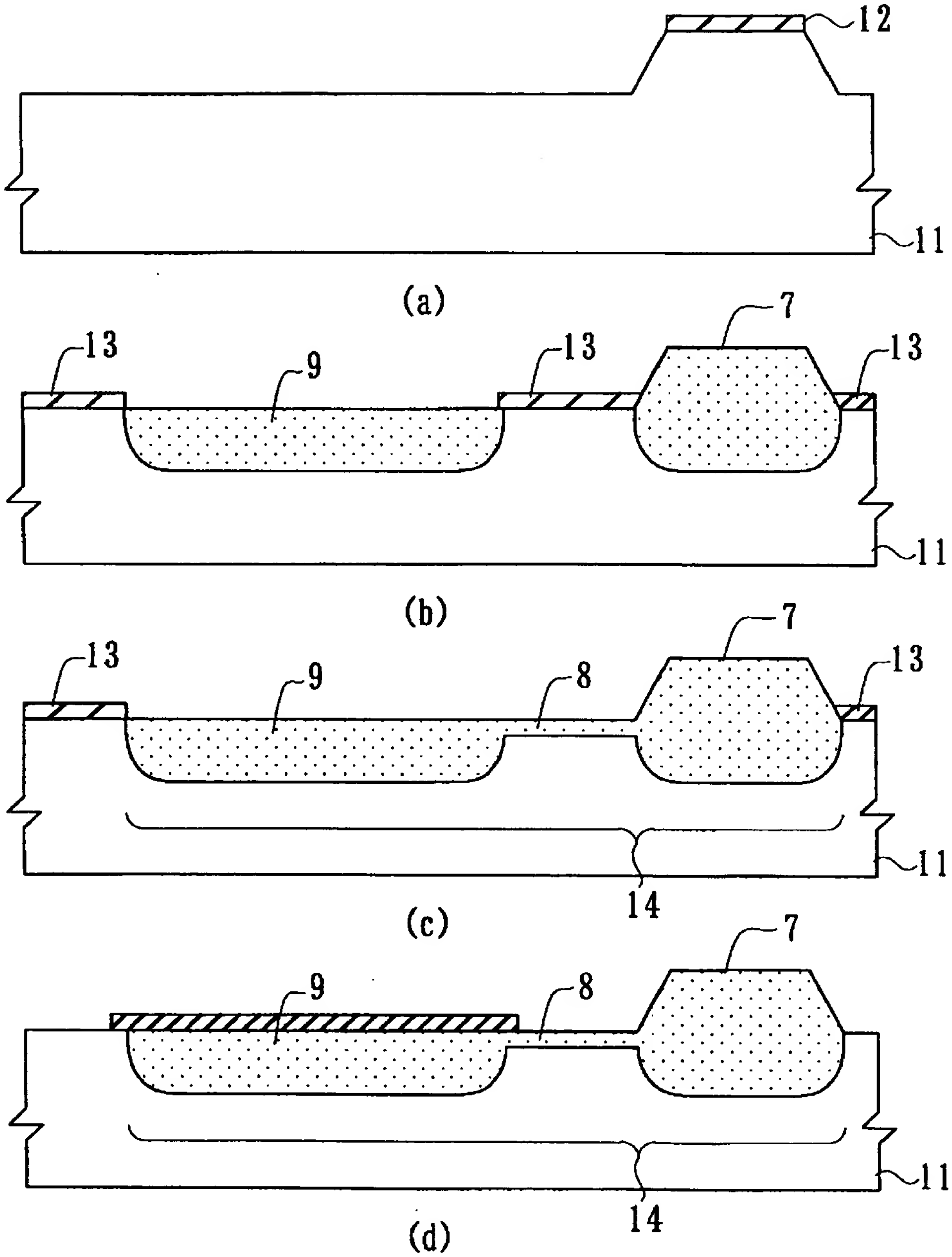


(a) FIRST EMBODIMENT

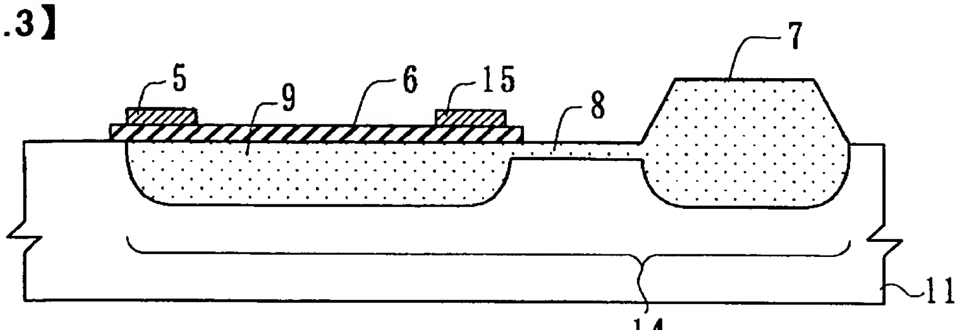


(b) CROSS-SECTIONAL VIEW TAKEN ALONG LINE A-A'

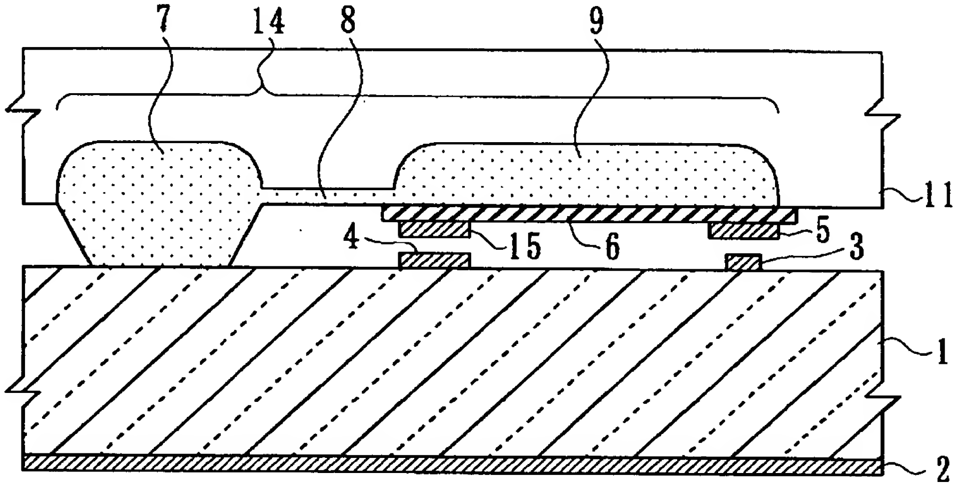
【Fig.2】



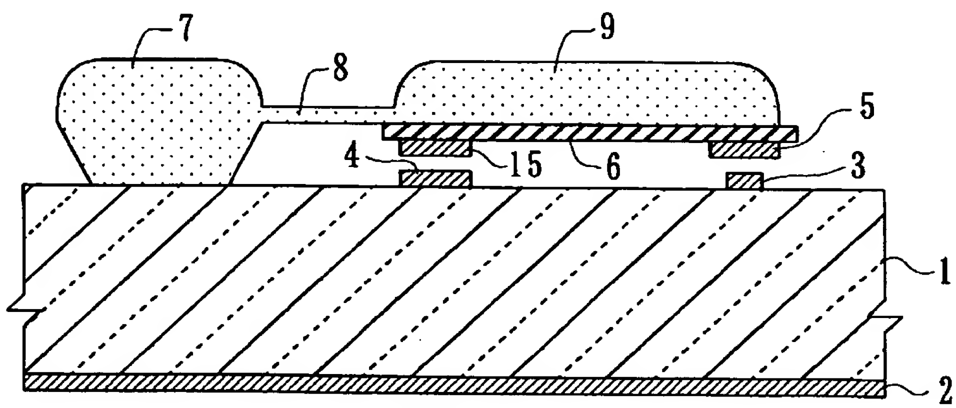
【Fig.3】



(e)

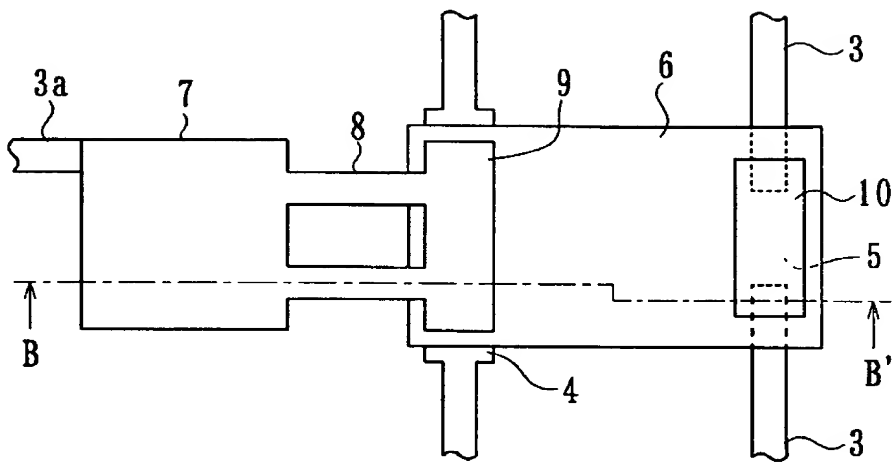


(f)

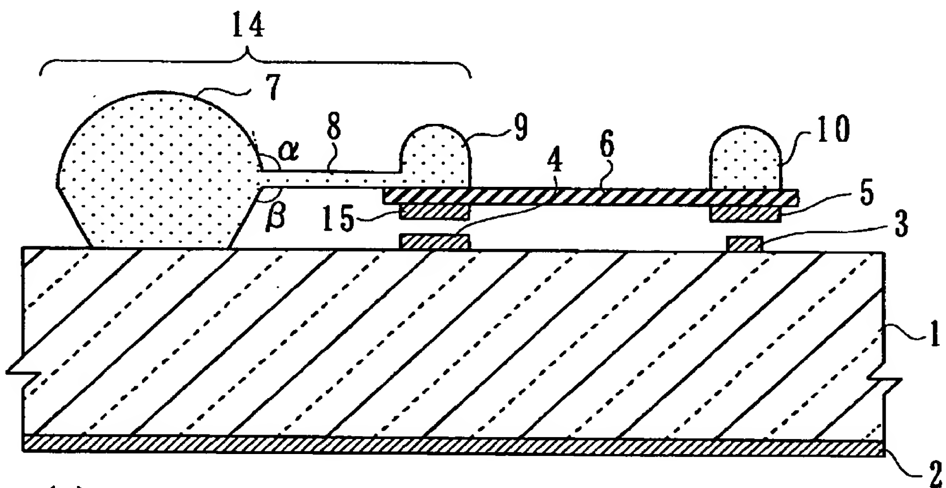


(g)

【Fig.4】

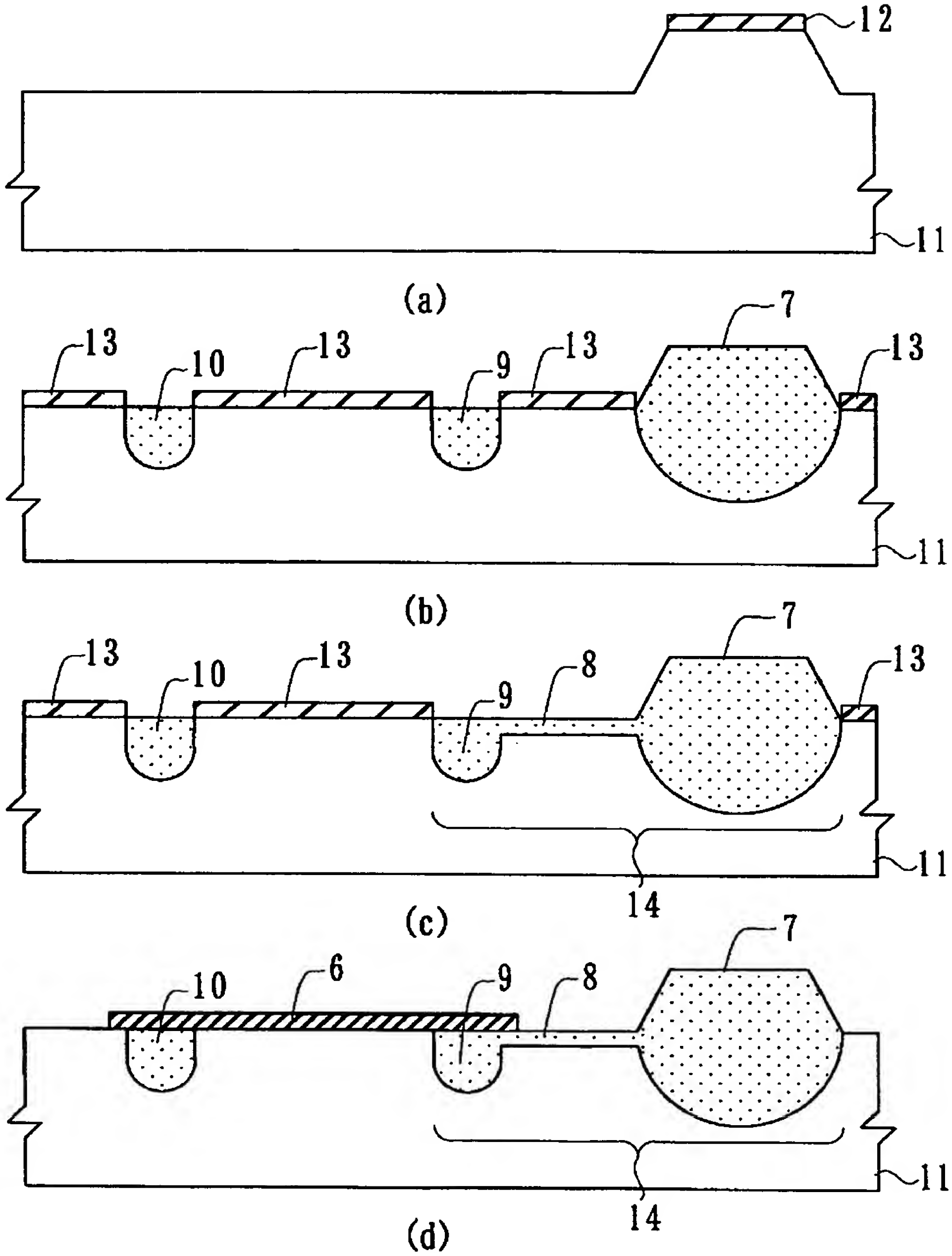


(a) SECOND EMBODIMENT

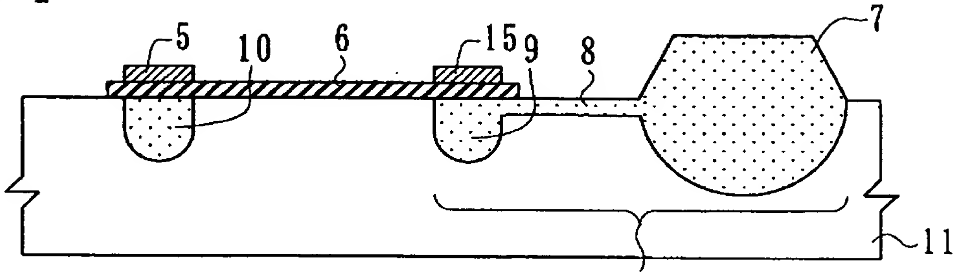


(b) CROSS-SECTIONAL VIEW TAKEN ALONG LINE B-B'

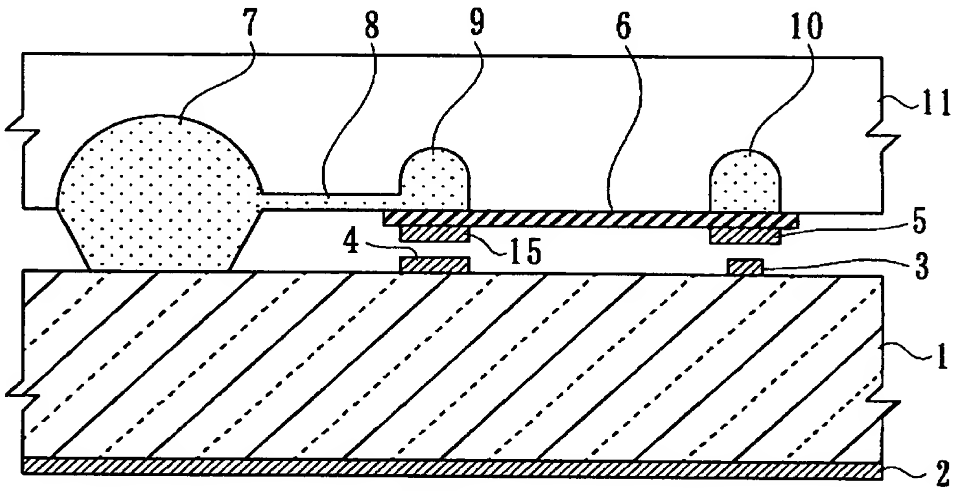
【Fig.5】



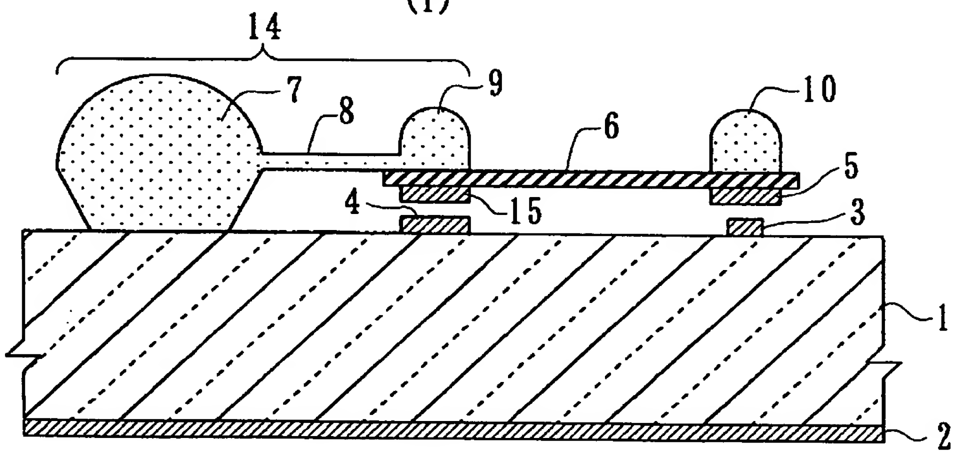
【Fig.6】



(e)

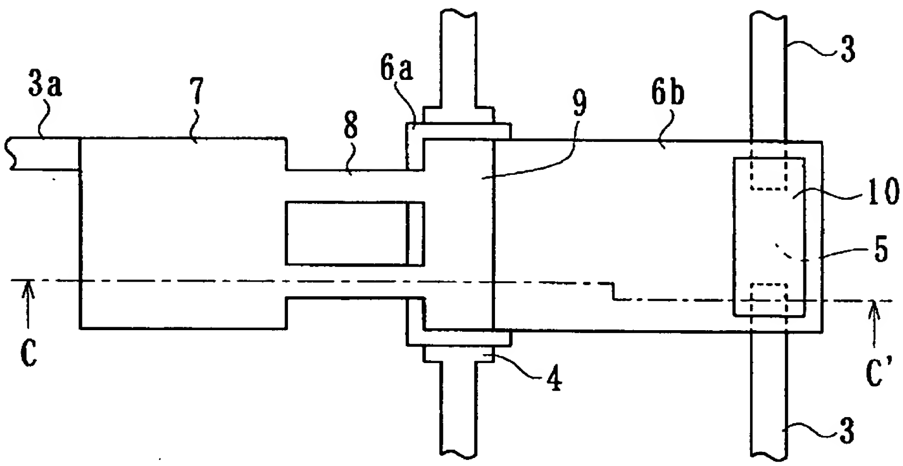


(f)

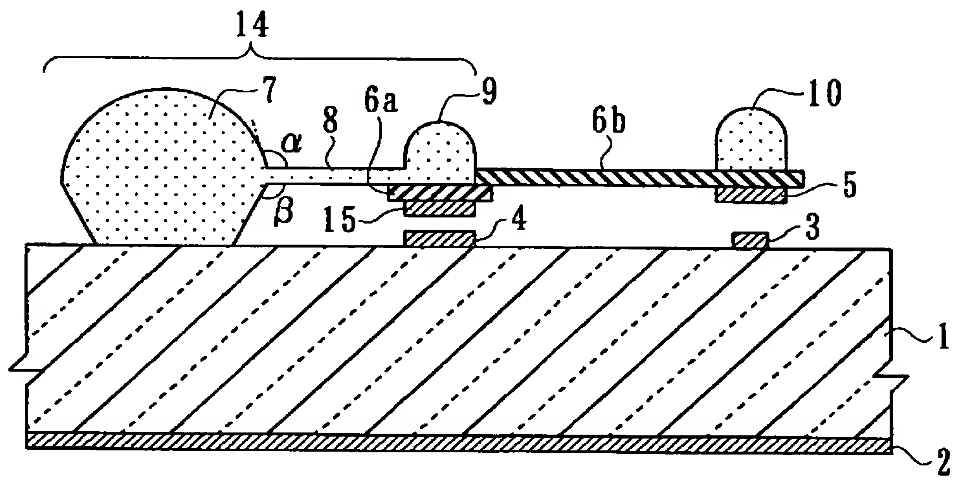


(g)

【Fig.7】

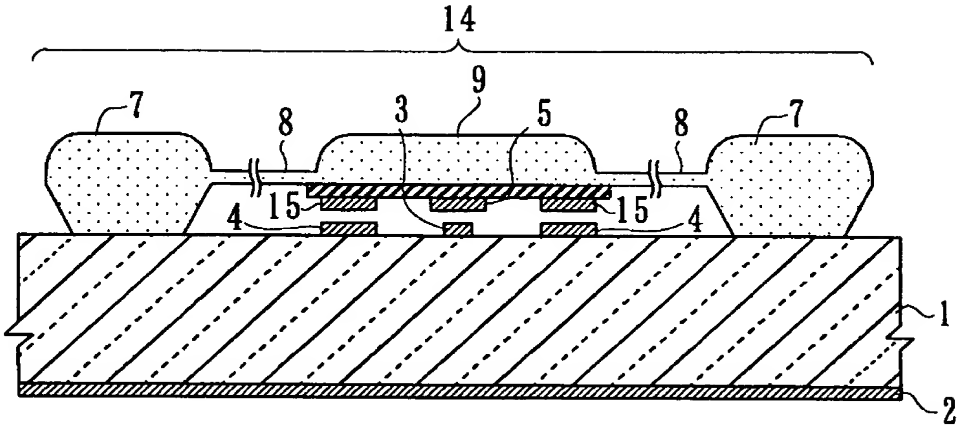


(a) THIRD EMBODIMENT



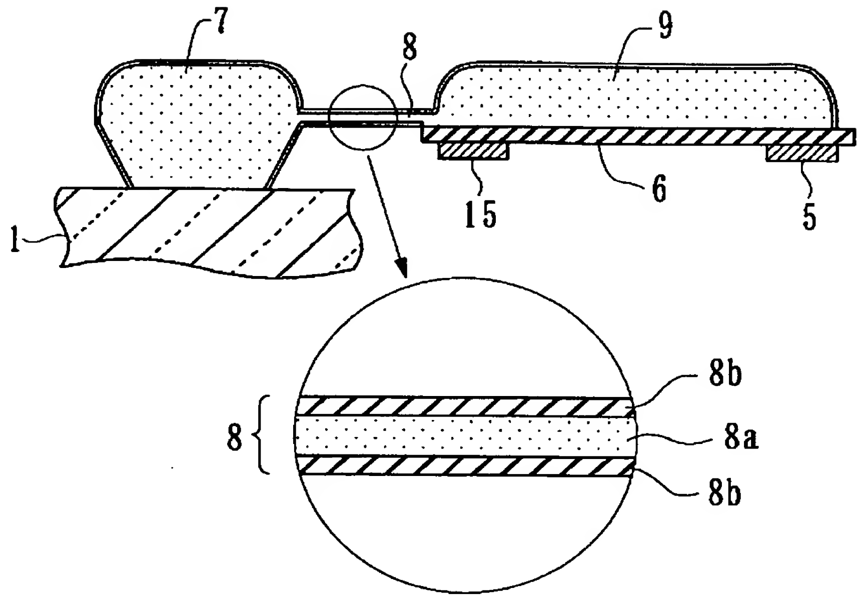
(b) CROSS-SECTIONAL VIEW TAKEN ALONG LINE C-C'

【Fig.8】



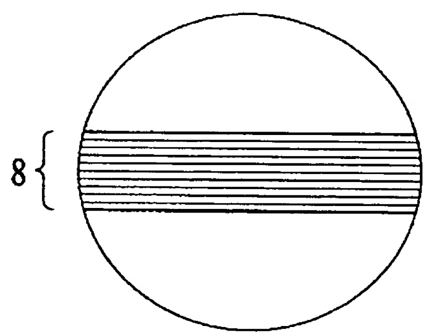
FOURTH EMBODIMENT

【Fig.9】



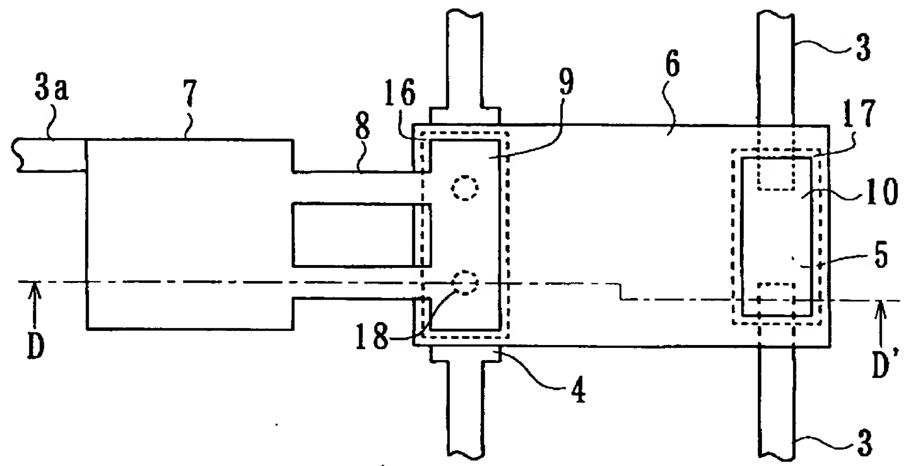
FIFTH EMBODIMENT

【Fig.10】

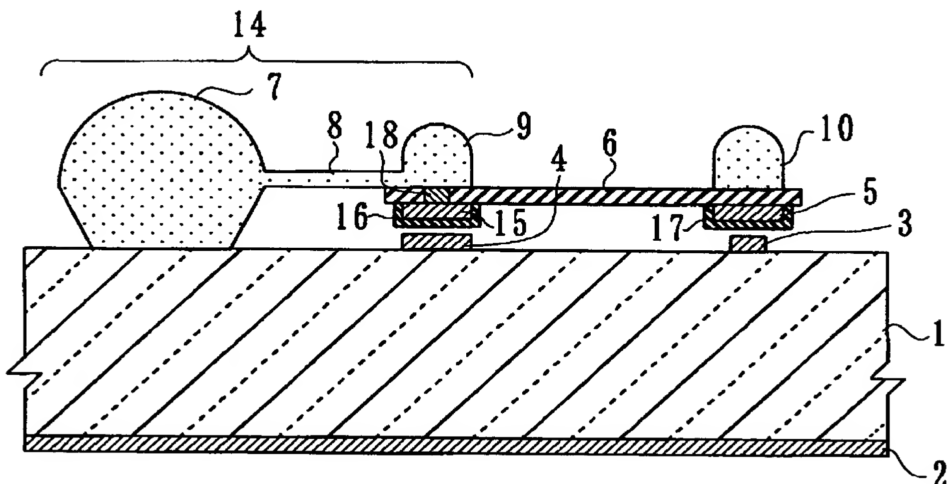


SIXTH EMBODIMENT

【Fig.11】

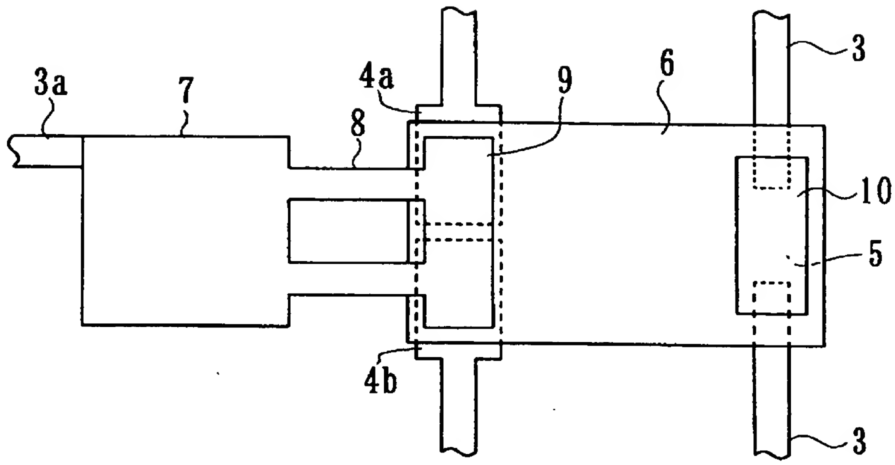


(a) SEVENTH EMBODIMENT



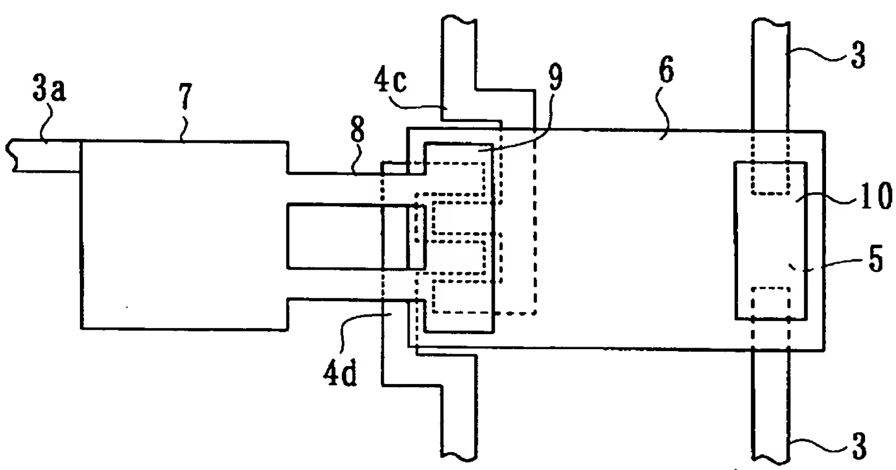
(b) CROSS-SECTIONAL VIEW TAKEN ALONG LINE D-D'

【Fig.12】



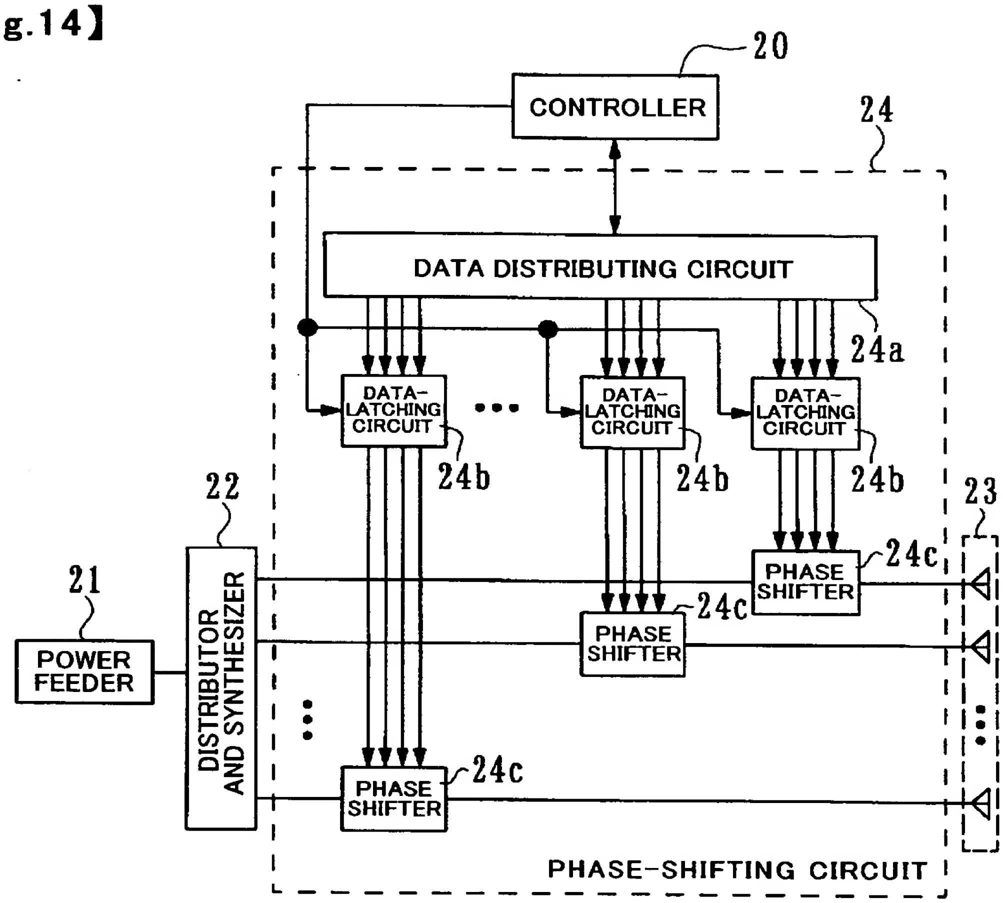
EIGHTH EMBODIMENT

【Fig.13】

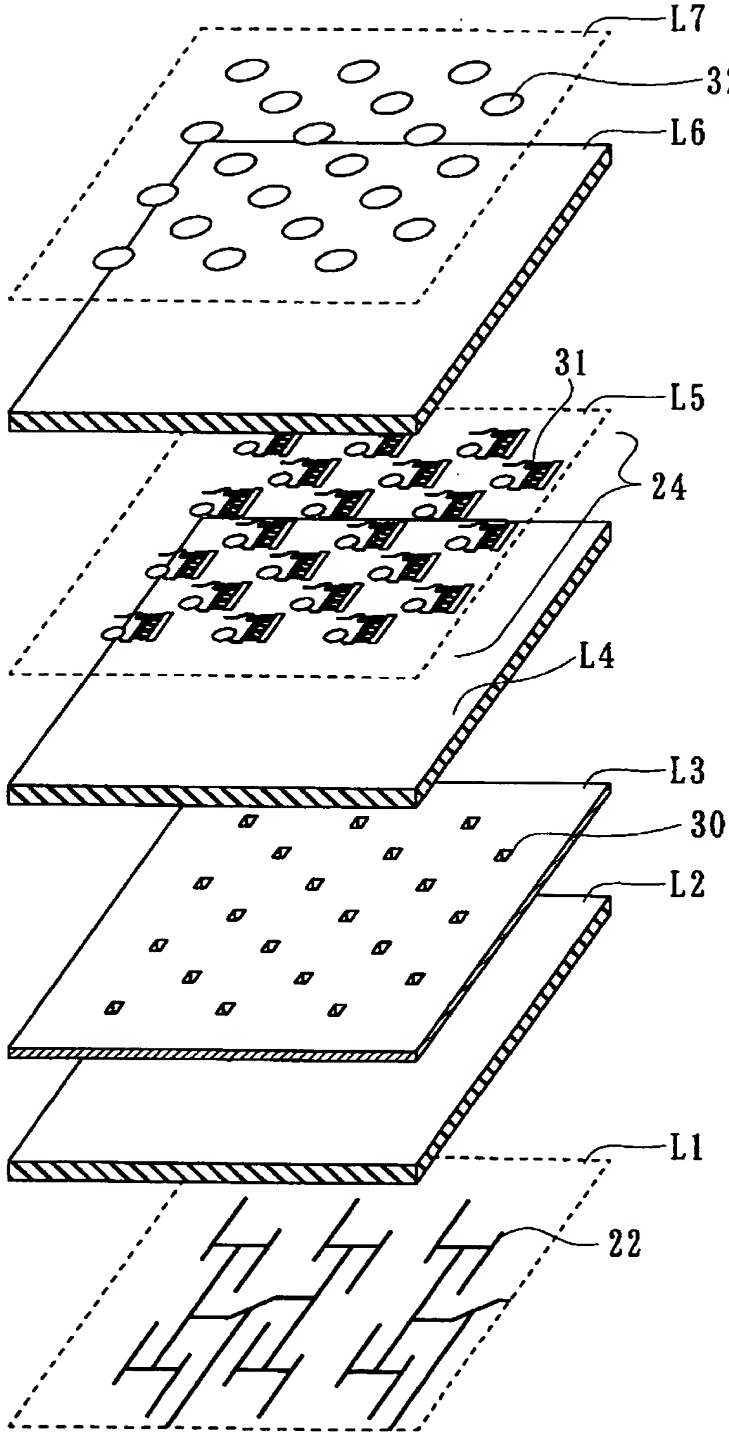


NINTH EMBODIMENT

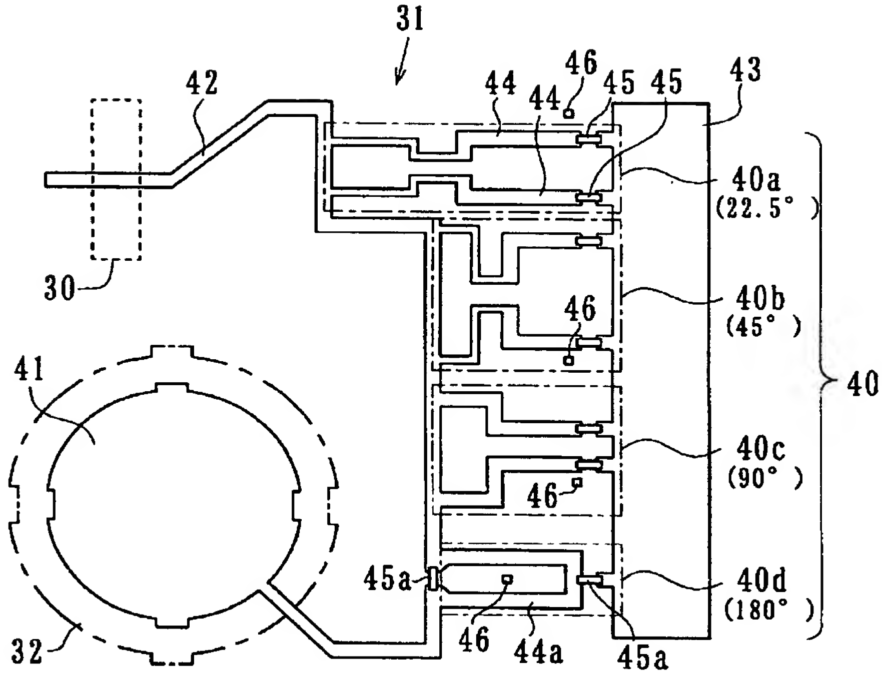
【Fig.14】


20
CONTROLLER
24
DATA DISTRIBUTING CIRCUIT
24a
DATA-LATCHING CIRCUIT
24b
DATA-LATCHING CIRCUIT
24b
DATA-LATCHING CIRCUIT
24b
22
23
21
POWER FEEDER
DISTRIBUTOR AND SYNTHESIZER
PHASE SHIFTER
24c
PHASE SHIFTER
24c
PHASE SHIFTER
24c
PHASE-SHIFTING CIRCUIT

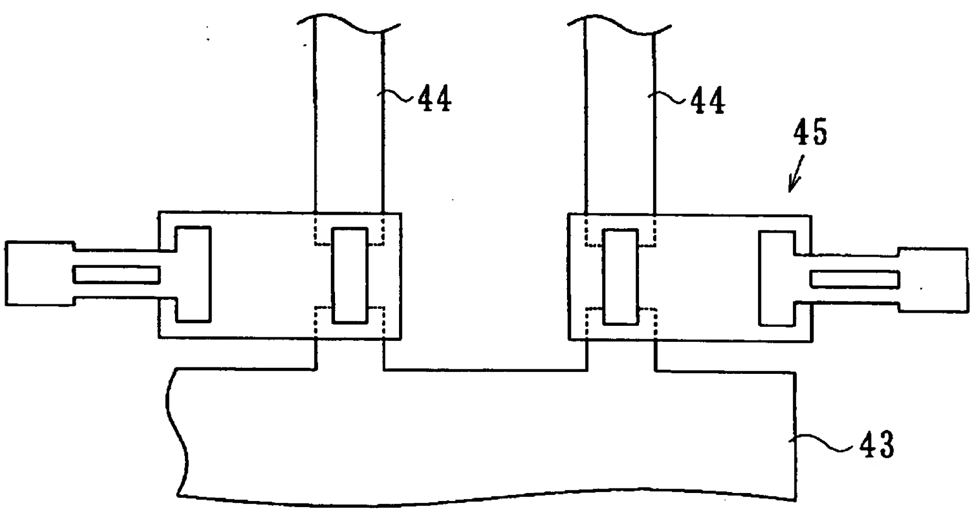
【Fig.15】



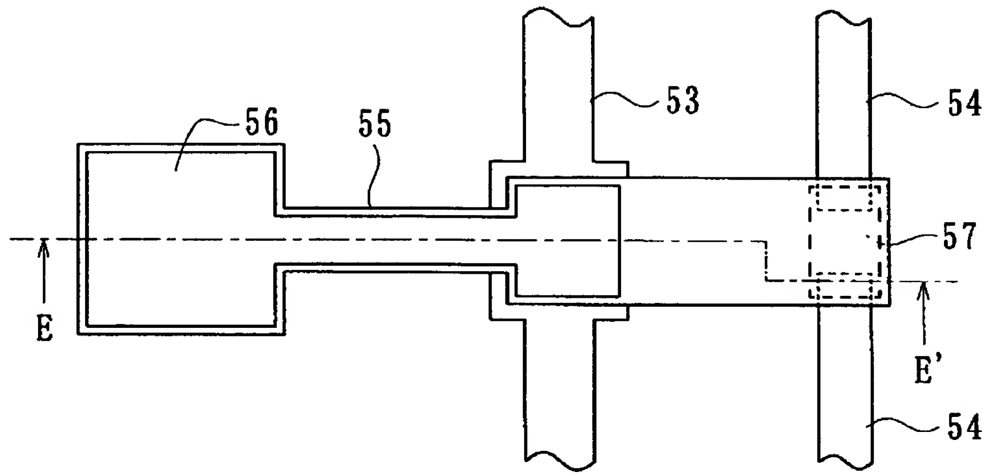
【Fig.16】


31
42
44
44
46
45 45
43
40a
(22.5°)
30
40b
(45°)
46
41
40
40c
(90°)
46
45a
40d
(180°)
32
46
44a
45a

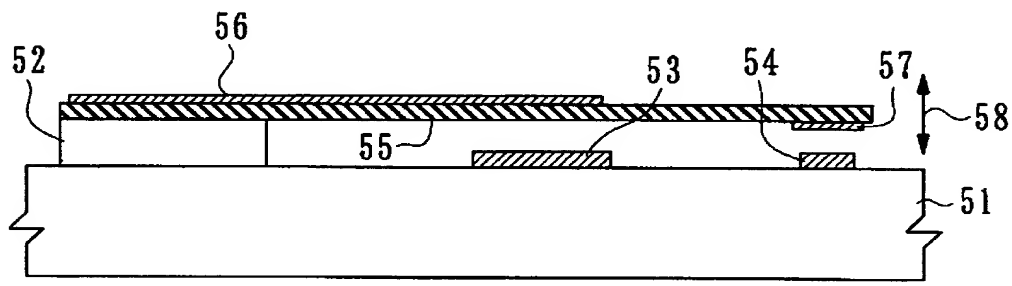
【Fig.17】


44
44
45
43

【Fig.18】



(a) CONVENTIONAL SWITCH



(b) CROSS-SECTIONAL VIEW TAKEN ALONG LINE E-E'